REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
04 Dec 2003		

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
United States Marine Corps Concepts of Link Employment Assessment Study	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Pennsylvania State University Applied Research Laboratory P.O. Box 30 State College, PA 16804-0030	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

See also ADM001601.

14. ABSTRACT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20040920 051

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*

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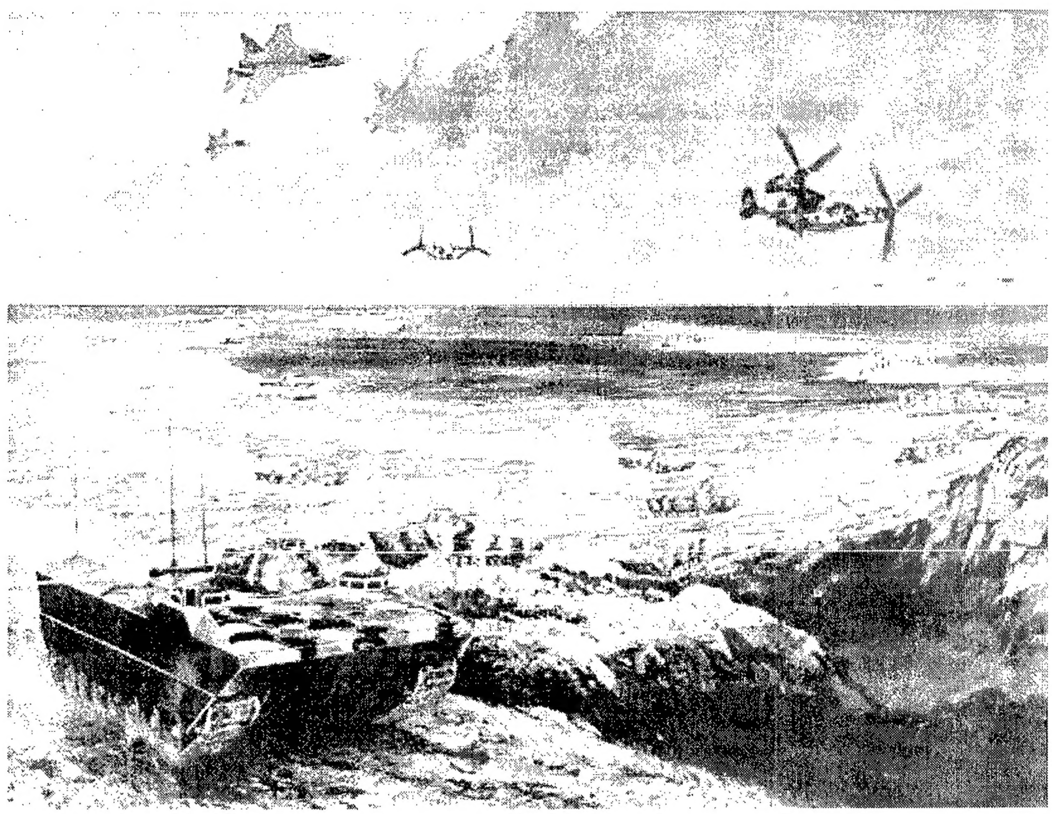
Marine Corps Research University

Final Report

United States Marine Corps Concept of Link Employment Assessment Study



TO SATISFY THE REQUIREMENTS OF

MCRU Contract No. M67004-99-D-0037
Delivery Order No. 0070

DATE

04 December 2003

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Acronyms

ABCS	Army Battle Command System
ABN	Airborne Node
ACE	Air Combat Element
ACN	Air Command Node
ACN	Airborne Communications Node
ACO	Airspace Control Order
ADB	Army Digitized Battlefield
AFATDS	Advanced Field Artillery Tactical Data System
AJCN	Adaptive Joint C4ISR Node
AMRAAM	Advanced Medium Range Air-to-Air Missile
AON	Air Operations Node
AS	Assault Support
ASC	Assault Support Coordination
ASCS	Air Support Control Section
ASN	Air Support Node
ASOC	Air Support Operations Center
ASPARCS	Air Surveillance and Precision Approach and Radar Control System
ATO	Air Tasking Order
BDA	Battle Damage Assessment
BLOS	Beyond Line of Sight
BLOS	Over The Horizon
BLS	Beyond Line of Sight
Bn	Battalion
C2	Command and Control
C2ISR	Command, Control, Intelligence, Surveillance and Reconnaissance
C2P	Command and Control Processor
C2PC	Command and Control Personal Computer
C3	Command, Control, and Communications

C4	Command, Control, Communications, and Computers
C4I	Command, Control, Communications, Computers and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAC2S	Common Aviation Command and Control System
CAS	Close Air Support
CC	Command Center
CDL	Common Data Link
CE	Command Element
CEC	Cooperative Engagement Capability
CID	Combat Identification
CLAWS	Complementary Low Altitude Weapons System
CLIP	Common Link Integration Processing
COC	Combat Operations Center
COE	Concept of Employment
COLE	Concept of Link Employment
CONUS	Continental United States
COP	Common Operational Picture
COTS	Commercial off the shelf
CP	Control Point
CSAR	Combat Search and Rescue
CSS	Combat Service Support
CSSD	Combat Service Support Detachment
CSSE	Combat Service Support Element
CTN	Composite Tracking Network
CTP	Common Tactical Picture
CU	Controlling Unit
DARPA	Defense Advanced Research Project Agency
DAS	Deep Air Support

DASC	Direct Air Support Center
dB	Decibel
DCA	Defensive Counter Air
DCOC	Digital Combat Operations Center
DCSS	Digital Communications Satellite Subsystems
DoD	Department of Defense
DSCS	Defense Satellite Communications System
EFV	Expeditionary Fighting Vehicle
EFV(C)	EFV-Command and Control variant
EFV(P)	EFV Personnel variant
EHF	Extremely High Frequency
ELB	Extending the Littoral Battlefield
EMW	Expeditionary Maneuver Warfare
EPLRS	Enhanced Position Location Reporting System
ERAST	Environmental Research Aircraft and Sensor Technology
ETCS	Expeditionary Tactical Communications System
EW	Electronic Warfare
EW/C	Early Warning/Control
FAC	Forward Air Controller
FAC(A)	FAC(airborne)
FARP	Forward Arming and Refueling Point
FDC	Fire Direction Center
FLIR	Forward Looking Infrared
FO	Forward Observer
FOC	Full Operational Capability
FoS	Family of Systems
FSCC	Fire Support Coordination Center
GCCS	Global Command and Control System
GCE	Ground Combat Element

GEO	Geostationary Earth Orbit
GIG	Global Information Grid
GIG-BE	GIG-Bandwidth Expansion
GOTS	Government off the shelf
HALE	High Altitude, Long Endurance
HALO	High Altitude Long Operation
HAPS	High Altitude Platform System
HF	High Frequency
HF-ALE	HF-Automatic Link Establishment
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IAS	Intelligence Analysis System
IBS	Integrated Broadcast Service
IOC	Initial Operational Capability
IP	Internet Protocol
JCTN	Joint Cooperative Targeting Network
JDN	Joint Data Network
JECCS	Joint Enhanced Core Communication System
JFACC	Joint Force Air Component Commander
JFC	Joint Force Commander
JLENS	Joint Land-Attack Cruise Missile Defense Elevated Netted Sensor System
JPN	Joint Planning Network
JRE	Joint Range Extension
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance and Target Attack Radar System
JTA	Joint Technical Architecture
JTF	Joint Task Force
JTIDS	Joint Tactical Information Distribution System
JTR	Joint Tactical Radio

JTRS	Joint Tactical Radio System
JVMF	Joint Variable Message Format
LAAD	Low Altitude Air Defense
LAV	Light Armored Vehicle
LAV-AD	Light Armored Vehicle – Air Defense
LCAC	Landing Craft, Air Cushioned
LEO	Low Earth Orbit
LOS	Line of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
MACCS	Marine Aviation Command Control System
MAGTF	Marine Air-Ground Task Force
MAW	Marine Air Wing
MCSLAP	Marine Corps Stationary Lighter than Air Platform
MEB	Marine Expeditionary Brigade
MEDEVAC	Medical Evacuation
MEF	Marine Expeditionary Force
MEO	Medium Earth Orbit
MFT	Message Format Translation
MHz	Megahertz
MIDS	Multifunction Information Distribution System
MIMO	Multiple Input, Multiple Output
MRRS	Multi-Role Radar System
NBC	Nuclear, Biological and Chemical
NCW	Network Centric Warfare
NLOS	Non Line of Sight
NSFS	Naval Surface Fire Support
OAAW	Offensive Anti Air Warfare
OC	Operation Center

OEO	Other Expeditionary Operations
OMFTS	Operational Maneuver From The Sea
ONR	Office of Naval Research
OTM	On The Move
OV	Operational View
PG	Participation Group
POP	Point of Presence
POP-V	Point of Presence - Vehicle
PPLI	Precise Participant Location and Identification
ROBE	Roll-On Beyond Line-of-Sight Enhancement
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SA	Situational Awareness
SADC	Sector Air Defense Commander
SADF	Sector Air Defense Facility
SATCOM	Satellite Communication
SCAR	Strike Coordination and Reconnaissance
SEAD	Suppression of Enemy Air Defenses
SHF	Super-high Frequency
SIAP	Single Integrated Air Picture
SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground and Air Radio System
SIPRNET	Secret Internet Protocol Router Network
SMART	Scalable, Modular, Airborne, Relay Terminals
SOA	Sustained Operations Ashore
SOF	Special Operations Forces
SSB	Single Side band
STOM	Ship to Objective Maneuver
SWARM	Surveillance Warfighting Array of Reconfigurable Modules
TAC	Tactical Air Controller

TAC(A)	TAC(airborne)
TACC	Tactical Air Command Center
TACP	Tactical Air Control Party
TADIL	Tactical Digital Information Links
TAOC	Tactical Air Operations Center
TCS	Transformational Communications Satellite
TCT	Time Critical Targeting
TDC	Theater Deployable Communications
TDL	Tactical Data Link
TDN/DTC	Tactical Data Network / Digital Technical Control
TRAP	Tactical Recovery of Aircraft and Personnel
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Air Vehicles
UGS	Unattended Ground Sensor
UHF	Ultra-High Frequency
UOC	Unit Operations Center
USAF	United States Air Force
USMC	United States Marine Corps
USMTF	United States Message Text Format
USN	United States Navy
VC	Vehicle Commander
VHF	Very-High Frequency
VMF	Variable Message Format
VTOL	Vertical Take-off and Landing
WAN	Wide Area Network
WARNET	Wide Area Relay Network
WNW	Wideband Network Waveform

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1 INTRODUCTION

The Marine Corps capstone operational concept, Operational Maneuver From The Sea (OMFTS), describes a marriage of maneuver warfare and naval amphibious operations. This is the centerpiece of our preparations for future expeditionary warfare.

OMFTS applies across the range of military operations, from major theater war to small-scale contingencies. It applies maneuver warfare to expeditionary power projection in naval operations as part of a joint or multinational campaign. OMFTS allows the force to exploit the sea as a maneuver space while applying combat power ashore to achieve operational objectives. The OMFTS concept embodies the Marine Corps Expeditionary Maneuver Warfare (EMW) concept in the context of expeditionary operations from a sea base.

1.1 Background

Ship-To-Objective Maneuver (STOM) is the tactical implementation of OMFTS by the Marine Air-Ground Task Force (MAGTF) to achieve the Joint Force Commander's operational objectives. It is the application of maneuver warfare to amphibious operations at the tactical level of war, and it is the conduct of combined-arms maneuver through and across the water, air, and land of the littoral battle space directly to inland objectives. STOM treats the sea as maneuver space, using it as both a protective barrier and an unrestricted avenue of approach. STOM is not aimed at seizing a beach for lodgment, but at projecting combat units ashore in their fighting formations and sustaining them to ensure mission accomplishment against a decisive objective. While the aim of ship-to-shore movement is to secure a beachhead, STOM thrusts Marine Corps forces ashore at multiple points in order to concentrate forces at the decisive place and time and in sufficient strength to enable success. This creates multiple dilemmas too numerous for an enemy commander's response, disrupts his cohesiveness, and diminishes his will or capacity to resist. This concept focuses the force on the operational objective, providing increased flexibility to strike the enemy's critical vulnerabilities. Seabasing much of the logistic support and some of the fire support reduces the footprint of forces ashore while maintaining the tempo of operations. Command and control (C2) capabilities allow commanders to control the maneuver of their units the moment they cross the line of departure at sea, this includes changing the axis of advance or points where they cross the beach during the assault.

Marine Aviation Command Control System (MACCS) Family of Systems (FoS) will play an important role in the fulfillment of the STOM mission. The operation centers (OCs) considered part of the FoS range from radar and missile systems in the near term to the Joint Strike Fighter (JSF) in the far term. Figure 1-1 illustrates the anticipated timeline for Full Operational Capability (FOC) for the MACCS FoS.

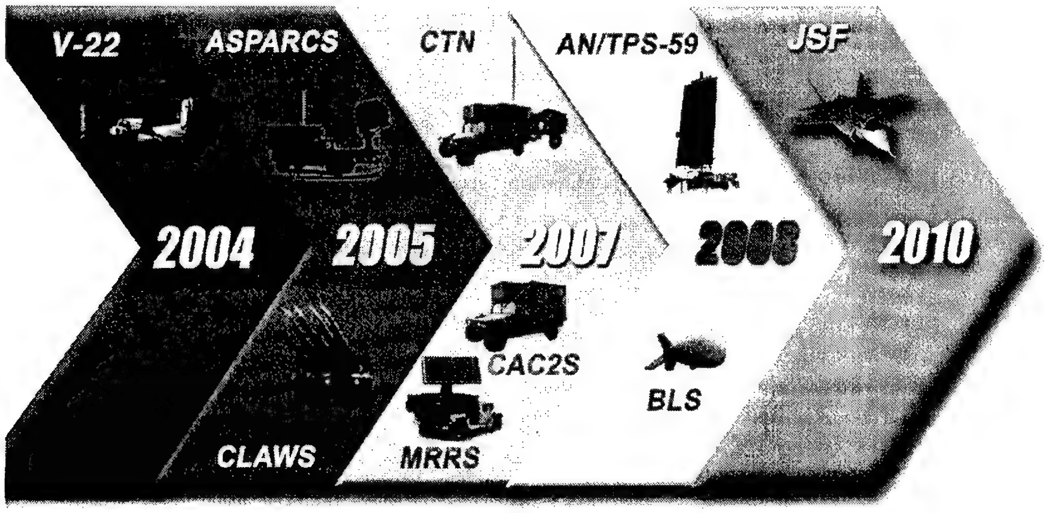

Figure 1-1 FOC timeframe for the MACCS family of systems

These systems will all interact as described by the operational view (OV) diagram shown in Figure 1.2.

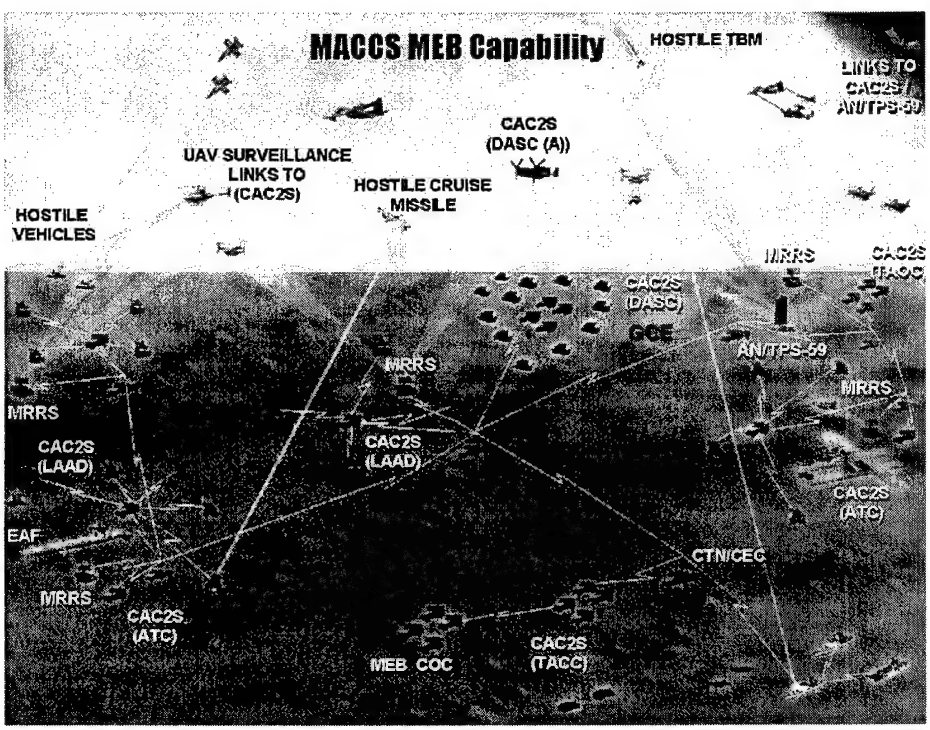

Figure 1-2 USMC Midterm MACCS Capability

1.2 Concept of Link Employment

This section introduces a coherent functional concept of MAGTF C2 at the operational level that facilitates the capstone Marine Corps Concept paper Operational Maneuver from the Sea. In order for the Marine Corps to transform itself into a true network centric fighting force as envisioned in Joint Vision 2020 there are several areas that need to be addressed.

Current architecture does not provide for a true network centric force. This is due to limitations in:

- Beyond Line of Sight (BLOS) communications
- lower echelon connectivity
- lack of fused data (i.e., there is no true common operational or tactical picture (COP/CTP))
- stove pipe systems are not interoperable with Joint and coalition forces
- no single C2 system
- lack of new system procurement and current equipment not viable to fulfill required roles.

The future looks bright with the eventual operational use of Joint Tactical Radio System (JTRS) and the associated equipment to enable all Joint and Service Command, Control, Communications, Computers and Intelligence (C4I) Strategies (Future Combat System (FCS), FORCEnet, Warfighter Information Network-Tactical (WIN-T), etc.) building an integrated data networking environment.

The objective architecture, shown schematically in Figure 1-3, is one where all data providers and subscribers reside on a common "network". Data providers such as sensor systems continuously push data onto the network backplane. Those interested in receiving data simply register a request for the items of interest. Any data meeting the culling criteria is then made available to the subscriber. For example, weapons systems require sensor (radar) inputs. The weapons system registers a request for radar data. All radar data is then made available to them. Similarly, the C2 functions also require radar data. With this architecture, the same data feeding the weapons systems is made available to the C2 arena. This provides for a step towards all assets having the same picture of the battlefield. An issue that immediately comes to mind is: "How do we know what data is available?" OSD is currently funding a horizontal fusion project. The project will include an information manager[1]. When a user first connects to the information server, they create a profile detailing their job information needs. This profile is then used to determine what information residing within the GIG will be of value to the registered user. Unfortunately, not all of these 'pieces' will be available in the near future.

In order for the Marine Corps to achieve network centric operations there must be a way to "bridge the gap" between what is today and what will be tomorrow. The solutions detailed in this document can build such a bridge.

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[1] The Ubiquitous Automated Information Manager, funded through the OSD Horizontal Fusion Office, is being developed at Penn State University's Applied Research Laboratory.

Prior to providing any solutions, one must understand what requirements and assumptions were used by the project team throughout the study. The following lists the fundamental requirements established by the project team during the development of these solutions:

- A BLOS/On-the-Move (OTM) connectivity is essential to mission success
- Single medium for voice, video, and data
- Chosen solutions must be interoperable
- Organic BLOS communications assets are preferable to leasing other assets
- Command posts/operation centers should operate wirelessly
- BLOS solution should be a combination of terrestrial, airborne and spaceborne platforms
- Any command post, either deployed or CONUS, should have the same operational picture

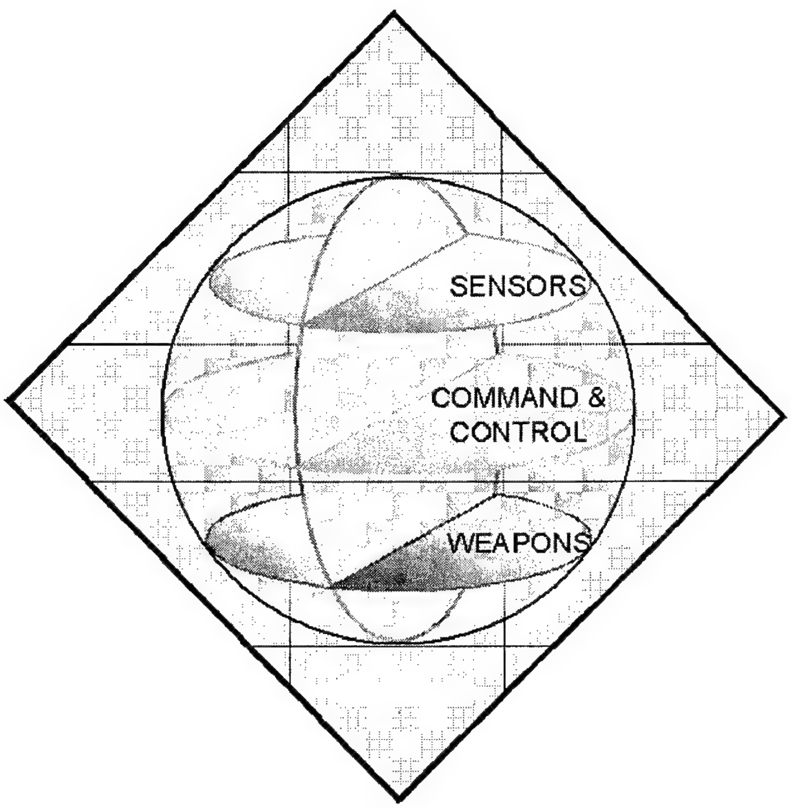

Figure 1-3 Objective Network Architecture

The following list details the basic assumptions required:

- Current and planned equipment should be used fully. The design and integration of new equipment is costly and delays the Marine Corps' Network Centric Warfare capability.
- Any new purchase requirements should be built from COTS/GOTS equipment to the fullest extent possible. This will minimize the time to operational capability as well as lower the ultimate costs.
- Solutions should be simple, affordable, scaleable and, when possible, should not require a significant research investment.
- MACCS FoS assets as well as other infrastructure, e.g., JTRS, will deploy as scheduled.
- BLOS solution should not be solely dependent upon satellites, nor should it be tied to manned or fixed location relay sites. All of these options have significant risks. For example, satellites may not be available when needed the most. Fixed relay sites are prime targets for an adversary.
- Relay nodes will be capable of operating in a self-organizing (ad hoc) network. JTRS radios, when relay enabled, will operate in an ad hoc manner. In addition, studies by John Hopkins University Applied Physics Laboratory indicate that an ad hoc network is ideal for this type of environment.

The remainder of this document addresses the issues identified in this study. Chapter 2 discusses the key enabling technologies required to fully realize JV 2020 and OMFTS operations.

Any chosen architecture must be interoperable with architectures being developed by the other services. Chapter 3 provides a summary of how the various services are addressing the data link architecture problem.

A major issue identified by the Marine Corps is their ability to communicate BLOS. Without this capability, no digital architecture will be adequate. Chapter 4 provides a summary of the BLOS problem as well as detailing various solutions. Finally, Chapter 5 summarizes the solutions detailed throughout the document and outlines a method to bridge between the current architecture and tomorrow's C2 architecture.

Information supplemental to the report is contained in three supplements under separate cover. The first supplement details how the authors view core aviation skills and how one can map the six functions of Marine Aviation to these core skills. The second supplement provides additional information about the operational centers discussed throughout the document. As part of this appendix, a discussion is provided about how each center may be employed with the functions of Marine Aviation. The final supplement details minimum implementation for the aviation function.

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2 KEY ENABLING TECHNOLOGIES

2.1 Joint Tactical Radio System

To date, each information transfer advancement has spawned a new, unique communications system. Majority of these systems are not interoperable. These systems are unique not only to the specific service, but also unique within the warfare domain, i.e., land, sea, air, SOF. This becomes even more problematic when a Joint/Coalition environment exists.

To achieve the specific and derived requirements of Joint Vision 2020 and the Global Information Grid (GIG) CAPSTONE Requirements Document requires a single interconnected, end-to-end information transport network to enable its vision of network-centric warfare and achieve the goals of information superiority and decision superiority. This network provides the communications transport, network operations and information assurance functions of the entire set of required information capabilities provided by the Global Information Grid. JTRS as the Department of Defense (DoD) designated network enabler of the deployed operational area, provides a critical piece of the GIG transport for the deployed force commander.[2]

JTRS is only one component network of the deployed portion of the GIG. JTRS will have critical interfaces with other GIG components, such as TCS, GIG-BE, Teleport, etc., as well as an integrated presence within such deployed networks as TDC-ICAP, DTC-TDN, WIN-T, etc. Figure 2-1, shows a view of the GIG transport layer as seen from a deployed perspective. The connectivity and elements show are not definitive, but represent a potential. The bottom-line is JTRS is a critical and fully integrated component of the GIG and must support the requirements of the GIG and Joint Vision 2020.

2.1.1 System Description

JTRS is a family of Joint Multi-Channel/Multi-Mode, Software-Defined, Reprogrammable Tactical Radio Systems. They have been designed to provide high capacity line of sight (LOS) and BLOS plain and secure voice, data, and video while operating in frequency bands from 2 MHz to 2 GHz. Digital information exchanges will be provided via internal networking protocol across the entire radio frequency (RF) band.

Figure 2-2 illustrates JTRS's basic operating premise. Conceptually, JTRS is two functional units. The top unit, JTRS Set, is the actual hardware. It consists of the processors, power, receivers, transceivers, etc. The second and most important piece is the software load. By loading a series of "CDs", one can make the radio function as a Single Channel Ground and Air Radio System (SINCGARS) radio or an automatic link establishment (ALE) style radio.

[2] Joint Tactical Radio System Joint Network Concept of Operations, Version 4.0, 1 July 2003.

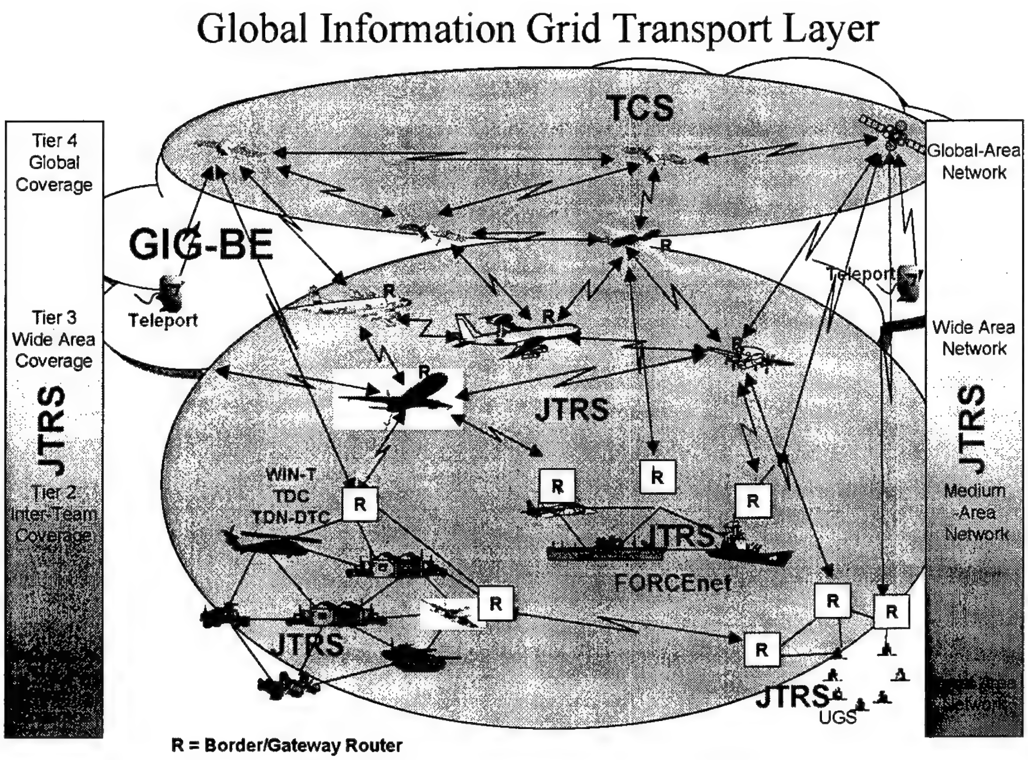

Figure 2-1 JTRS and the Global Information Grid

2.1.1.1 Capability Provided

JTRS will provide a wideband digital waveform to support the integration of aviation, mechanized, motorized and dismounted forces not achievable today. In addition, the multiband, multimode radios will allow for a more flexible employment of forces and provide communication interoperability. The Marine Corps is currently working the development, procurement, and integration of Ground Vehicular JTR sets, and the development of Manpack/Handheld.

The JTRS program promises to solve many of the C2 problems for the USMC as they move towards true NCW. JTRS will simplify the C2 architecture by providing one radio that can fulfill the current requirement for many radios. JTRS is an integrated solution to support aviation, mechanized, mobile, and dismounted forces and will provide embedded networking and information security. Ground domain variants will provide vehicle, manpack, and hand-held radios.

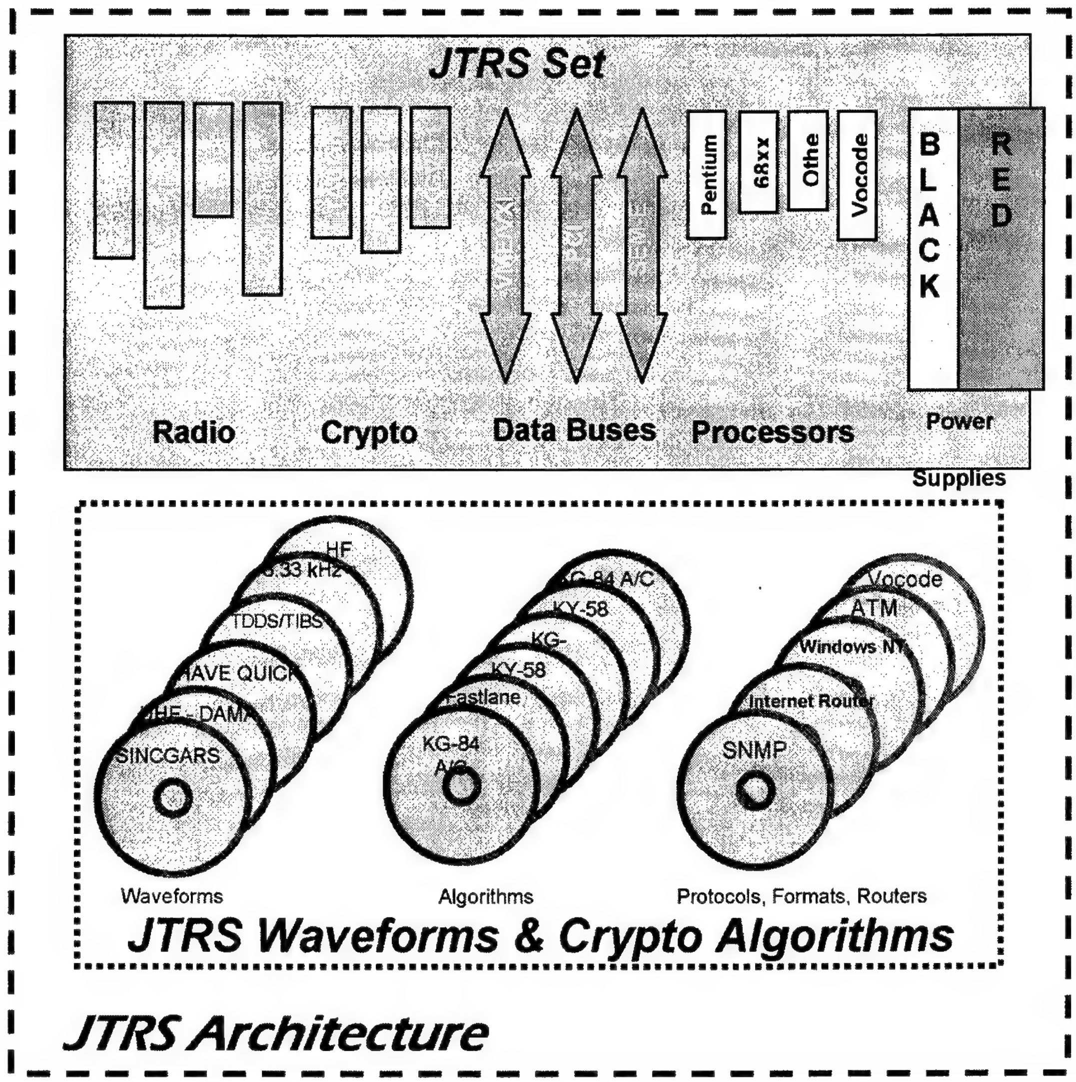

Figure 2-2 JTRS Operating Architecture

Current radio systems provide insufficient data throughput to support exchange of command and control and fire support data. JTRS will provide a wideband networking waveform (WNW) to support the communication requirements of the warfighter not achievable today. In addition, the multi-band, multi-mode radios will allow for more flexible employment of forces and allow for exchange of information.

2.1.1.2 Basic Acquisition Strategy

The JTRS acquisition strategy, Figure 2-3, will be evolutionary in nature with the Cluster 1 (vehicular) variant as the initial core capability to be fielded. By definition, the JTRS design is modular in structure and contains provisions for future upgrades, as the software waveforms are refined. Because JTRS is a high technology and software intensive program, it is well suited to

an evolutionary strategy. The follow-on capabilities to be fielded will be the manpack and hand held variants when they become sponsored, defined, and available. Currently, SOCOM is the designated lead for both of these variants.

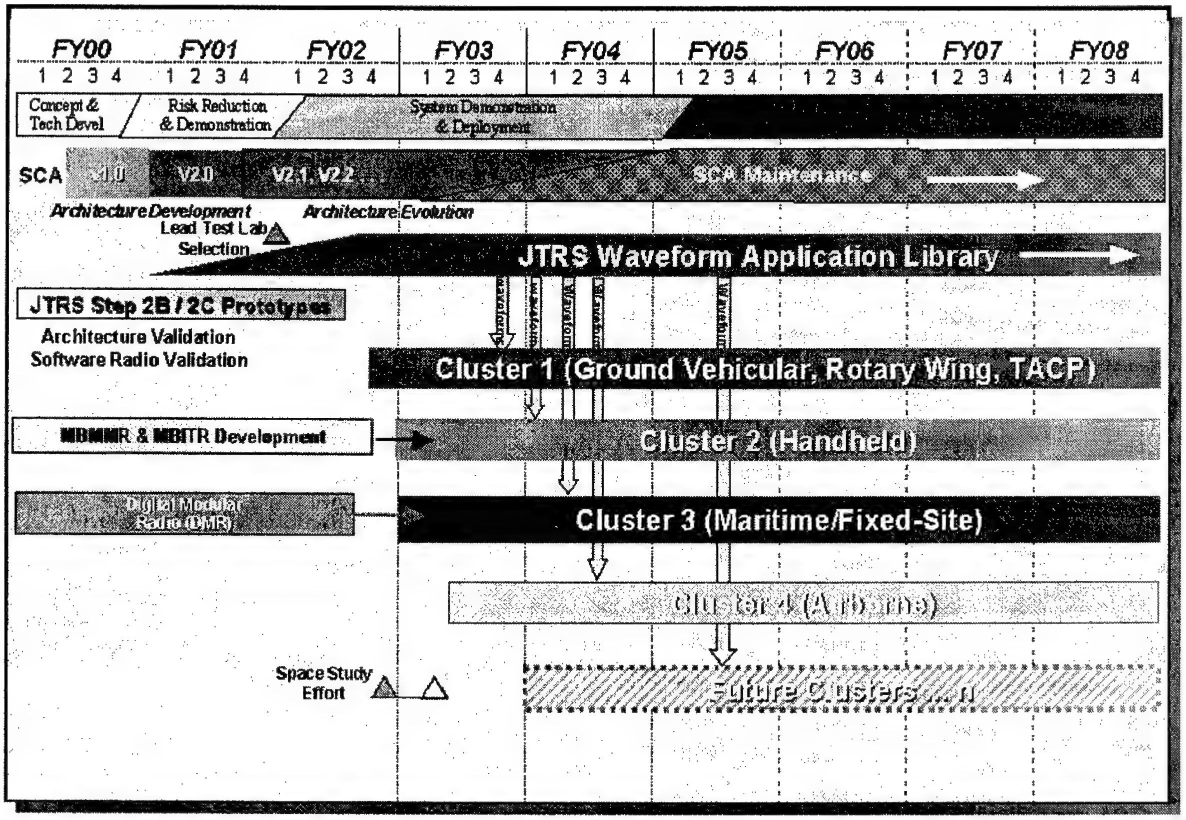

Figure 2-3 JTRS Acquisition Schedule

2.1.1.2.1 Cluster 1

For Cluster 1 (vehicular), the AN/MRC-138 was chosen as the fielding baseline because it corresponds to the first available JTRS variant, is in immediate need of replacement, is spread throughout the Marine Corps ground domain. By replacing this item first, the greatest number of USMC personnel will be exposed to, trained on, and gain operational experience with the JTRS in the shortest possible time. Cluster initial operational capability (IOC) is scheduled for FY06.

2.1.1.2.2 Cluster 2

Cluster 2 will provide JTRS in hand held and manpack formats. The initial (Block 1) radios will operate between 20 and 512 MHz. The radio will have the following waveforms: SINCGARS, HQII, VHF AM/FM, and UHF AM/FM. User locations will be relayed in either GPS or MGRS coordinates. Cluster IOC is scheduled for FY04/05.

2.1.1.2.3 Cluster 3

Cluster 3 will provide JTRS to maritime (sea based) platforms as well as fixed sites. The radio is planned to be: digital, modular, software programmable with four or more channels, multi-function, and cover multiple bands between 100 KHz-2 GHz. Block 1 IOC is scheduled for FY04/05.

2.1.1.2.4 Cluster 4

Cluster 4 will replace airborne asset radios. The basic design is similar to Cluster 3 radios with one exception. The airborne radio will have eight channels rather than the four in the maritime variant. Cluster IOC is yet to be determined.

2.1.2 Impact on USMC

The tables[3] below details which USMC radio systems will be replaced within each cluster set.

Table 2-1 Systems Impacted in Cluster 1

# Fielded	# to be Purchased	Nomenclature	Description
5620	5144	ARC-210	Airborne VHF/UHF/SINCGARS
0	0	ARC-232	STARFIRE UHF/VHF LOS Radio
409	0	GRC-193	Ground HF SSB
0	0	GRC-229	Ground EPLRS
1175	0	MRC-138	Mobile HF SSB
1509	0	MRC-145A	Vehicular 2-channel SINCGARS
3379	0	PRC-104	Manpack HF/SSB
465	0	PRC-138	Manpack HF ISB, SSB part of ISHMRS
138	0	TRC-170(V)	Digital Tropo-Scatter Radio Terminal
0	0	TSQ-129	PLRS Master Station
12099	0	VRC-87 to 92	Ground
0	0	VSQ-1	Vehicular PLRS
1171	0	VSQ-2	Vehicular EPLRS

[3] JTRS Joint Program Office, 15 Jan 2003.

Table 2-2 Systems Impacted in Cluster 2

# Fielded	# to be Purchased	Nomenclature	Description
0	0	ASQ-177	PLRS
4024	0	AN/PRC-68	
3379	0	PRC-104	Manpack HF/SSB
0	0	PSQ-4	Manpack PLRS
0	0	PSQ-6	Manpack EPLRS
0	10	TSQ-158	EPLRS
0	0	VSQ-1	PLRS

Table 2-3 Systems Impacted in Cluster 3

# Fielded	# to be Purchased	Nomenclature	Description
2	0	ARC-94	
9971	0	ARC-182	
441	0	AN/MRC-142	
303	0	URC-107	JTIDS Class 2 and 2H Terminals

Table 2-4 Systems Impacted in Cluster 4

# Fielded	# to be Purchased	Nomenclature	Description (User)
45		ARC-51	Airborne UHF
0		ARC-200	HF/SSB Airborne

Figure 2-4 illustrates the operational view of the battlefield once cluster 1 has been completed.

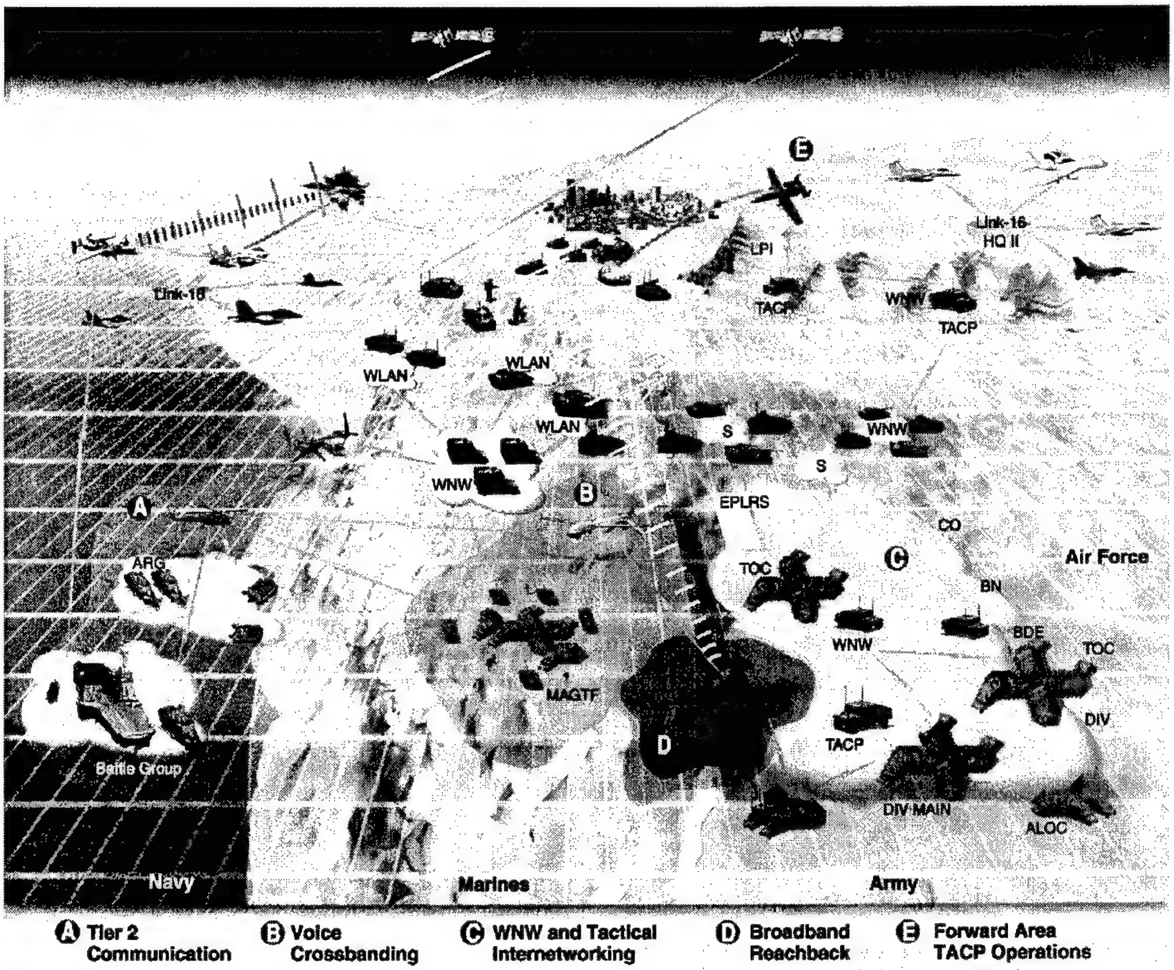

Figure 2-4 Cluster 1 Operational View

2.1.3 JTRS Shortfalls

Several issues need to be addressed by the aviation community to assure JTRS will bring the required capabilities needed to support Marine aviation.

- Extend range of JTRS to include an BLOS capability. Effective from over the next hill out to a range of 400 nm.
- Change focus to support Battalion and below – interoperable with JTRS.

Should not require terrestrially based infrastructure (relay sites, etc.) that require additional manpower that will increase force protection and security requirements.

The JTRS has the potential to be the key component of the USMC C2 architecture. However there is no requirements document identifying the services needs for JTRS's Message Format Translation (MFT) capability. This capability can provide the necessary gateway functionality needed by the USMC and DoD community at large.

The "front end" piece (that which displays the waveform into a user usable display) of JTRS is not well defined or planned for.

2.2 Ad Hoc Networks

This section describes a technology that can be implemented in ground based systems as well as airborne systems. Fundamentally, one is establishing a network composed of all available assets. The architecture preferred for a "battlefield environment" is an ad hoc network. An ad hoc network is preferred for the following reasons:

- Supports mobility
- Avoid single point of failure common with typical centralized systems
- Given that existing infrastructure is potentially unreliable, need an architecture that is self healing and self organizing
- Rapidly deployable since the network itself is created on-the-fly
- Multi-hop packet routing used to exchange messages between transient nodes which may or may not be with LOS of each other
- Route between two hosts can be selected based upon a minimum quality of service or minimum transmission speed.
- Timing and data management issues are automatically handled via low level supporting network protocols.

2.2.1 Background

Mobile ad hoc networks are self-organized networks. Communication in ad-hoc network does not require existence of a central base station or a fixed network infrastructure. Each node of an ad-hoc network is the destination of some information packets while at the same time it can function as relay station for other packets to their final destination. This multi-hop support in ad-hoc networks, which makes communication between nodes outside direct radio range of each other possible, is probably the most distinct difference between mobile ad hoc networks and wireless LANs. A mobile ad hoc network may be connected at the edges to the fixed, wired Internet. In this case, mobile ad hoc networks expand the present Internet and wireless access to Internet.

Examples of potential practical use of mobile ad-hoc networks are only limited by imagination. Ad hoc networks perfectly satisfy military needs like battlefield survivability, operation without pre-placed infrastructure and connectivity beyond the line of sight. For monitoring and measuring purposes, a large number of small computing devices could be spread over a hostile or unknown terrain (sensor dust) to form a self-sustained ad-hoc network.

2.2.2 Implementation

Figure 2-5 illustrates a notional ad hoc network. In practice, the WAN Gateways are the tactical tie in to the internet. The mobile nodes can be anything from a single Marine on the ground to a fast moving JSF. In an ad-hoc network, the Marine's as well as the JSF radio know what other nodes they can talk to. The radios are able to route a given data element from one "box" (radio) to its final destination. Since the network is self-organizing, it does not matter if the JSF moves from one physical routing network to another as it receives data. In the figure below, the two lower nodes communicate through the upper nodes to get a message to the upper right node. As the boxes move around, the communication path (depicted by the black line) would change.

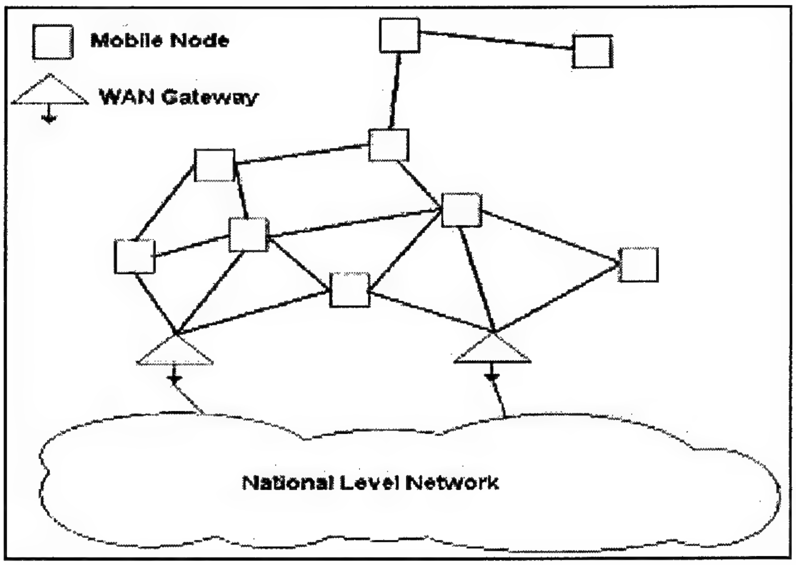

Figure 2-5 Notional Ad Hoc Network

DoD has several reasons for desiring these networks:

- Need for Battlefield survivability
- Military cannot rely on access to a fixed pre-placed communication infrastructure in battlefield
- Use of ad hoc networks will increase mobility and flexibility. Ad hoc networks can be brought up and torn down in very short periods of time.
- Ad hoc networks are more robust than conventional wireless networks because of their non-hierarchical distributed control and management mechanisms.
- Because of short communication links (node-to-node instead of node to a central base station), radio emission levels could be kept at low level. This increases spectrum reuse possibility, possibility of using unlicensed bands, lower probability of detection.

- Because of multihop support in ad-hoc networks, BLOS communication is possible at high frequencies. Traditionally, distance between nodes is the controlling factor in LOS communications. In addition to distance, terrain, foliage, and man-made obstacles can also prevent LOS connectivity. Ad hoc networks become even more desirable in these environments as each individual Marine becomes a potential relay hop.

Figure 2-6 illustrates how the ad hoc network scheme fits within the entire battlefield tactical network. As mobility increases, one must transition from a wired and/or local area wireless network to a true wireless ad hoc style network. Ad hoc networks are designed to work where the nodes are very mobile, e.g., tanks, trucks, jets, Marines, etc.

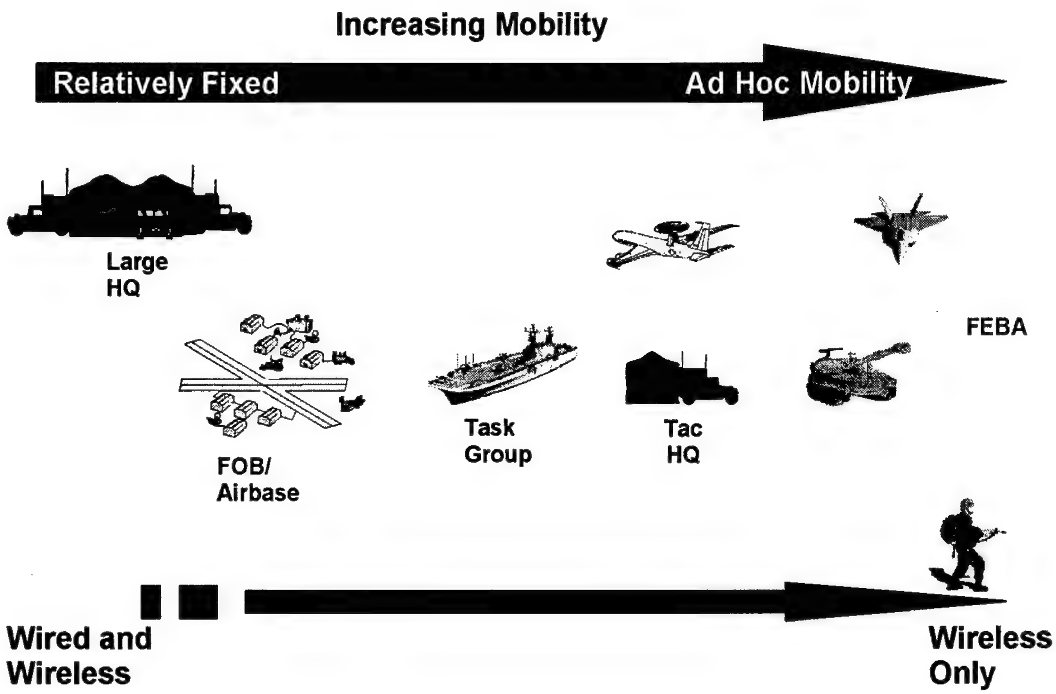

Figure 2-6 Mobility vs. Connection Type in the Battlefield

2.3 Gateways

Gateways in general provide an ability to parse messages and transform them from one message format into a different message format. Additionally, gateway products may include an ability to interface to a radio(s), or radio sub-system(s), and require a user interface to allow the user or system administrator to initiate the radio interfaces as part of the gateway initialization process.

Link-16/Variable Message Format (VMF) participants use non-interoperable message sets and media for information exchange. The gateway facilitates interoperability by enabling information

exchange over whichever means are available to data link participants -- from the most time-sensitive threat data to the lowest priority general intelligence information.

The figure below illustrates a trivial gateway. In this case (going left to right), Link 16 data from a piece of hardware is translated on a laptop to VMF format. The message is then retransmitted over a different radio in the new format.

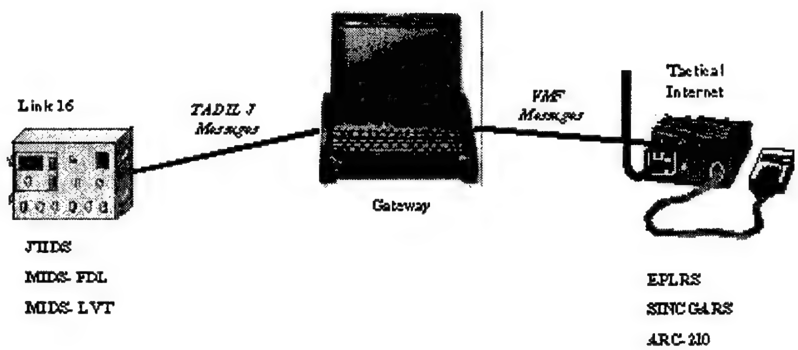

Figure 2-7 Trivial Link 16/VMF Gateway

Another type of gateway simply takes a waveform at a given frequency and retransmits the same waveform at a different frequency range. The Navy implements such a gateway to provide Link 16 extension between distant ships. In this case, the Link-16 data is retransmitted in the UHF band to a satellite. The satellite then relays the information back down to the distant point where the ship will translate the message from UHF to standard Link-16 frequency band. This is illustrated graphically in Figure 2-8.

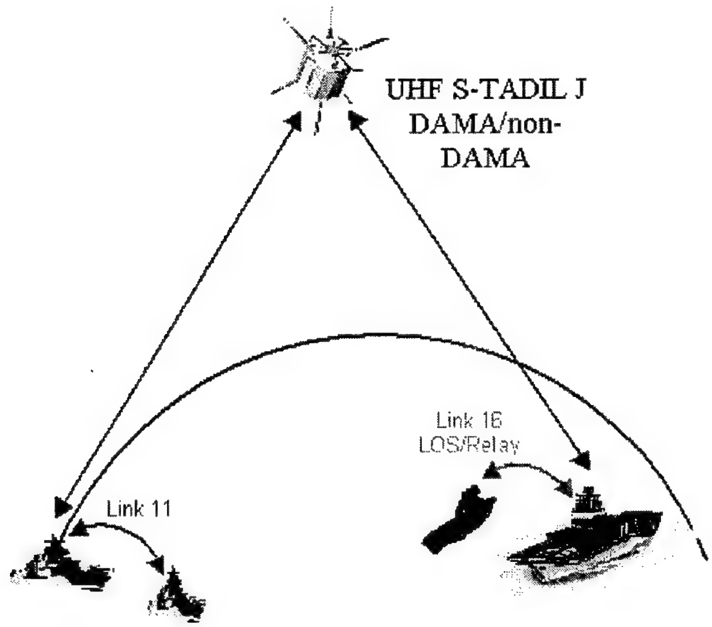

Figure 2-8 Link-16 Frequency Gateway

2.4 Network Centric Warfare

Network-centric operations are military ***operations*** that are enabled by the networking of the force. Network-centric operations provide a force with access to a new, previously unreachable region of the information domain. The ability to operate in this region provides warfighters with a new type of information advantage, an advantage broadly characterized by significantly improved capabilities for sharing and accessing information. Network-centric ***warfare*** (NCW) enables warfighters to leverage this information advantage to dramatically increase combat power through self-synchronization and other network centric operations.

Across a broad spectrum of mission areas, evidence for the power of network-centric warfare is emerging from experiments and exercises. Evidence collected to date supports a strong correlation between information sharing, improved situational awareness, and significantly increased combat power. A common theme in this evidence is the critical role of modified tactics, techniques and procedures, in enabling warfighters to effectively leverage their new information advantage.

Network-centric operations focus on the tactical and operational levels of warfare, but they impact all levels of military activity from the tactical to the strategic. At the operational level, network-centric operations provide commanders with the capability to generate precise warfighting effects at an unprecedented operational tempo, creating conditions for the rapid lockout of adversary courses of action.

Figure 2-9 below illustrates the two IP-connected networks in the battlefield. The top network consists of the airborne and spaceborne assets. The terrestrial assets are also connected to a network. The two networks are interconnected at various "relay" nodes.

An IP-based configuration allows for enhanced dissemination of information in a shared battlespace environment. As the number of operational nodes on the network grows, warfighters will expand the edge of their battlespace network to include today's "disadvantaged" users—shooters, individual ground troops, weapons, and more. This emerging network will utilize a heterogeneous set of physical links, including RF LOS, RF BLOS, (SATCOM), Optical LOS, and Optical BLOS links to interconnect terrestrial, air, and space platforms. By using an addressing scheme based on the internet protocol, users will be provided the means of addressing other elements of the network, regardless of physical medium used for transmission, or where they operate.

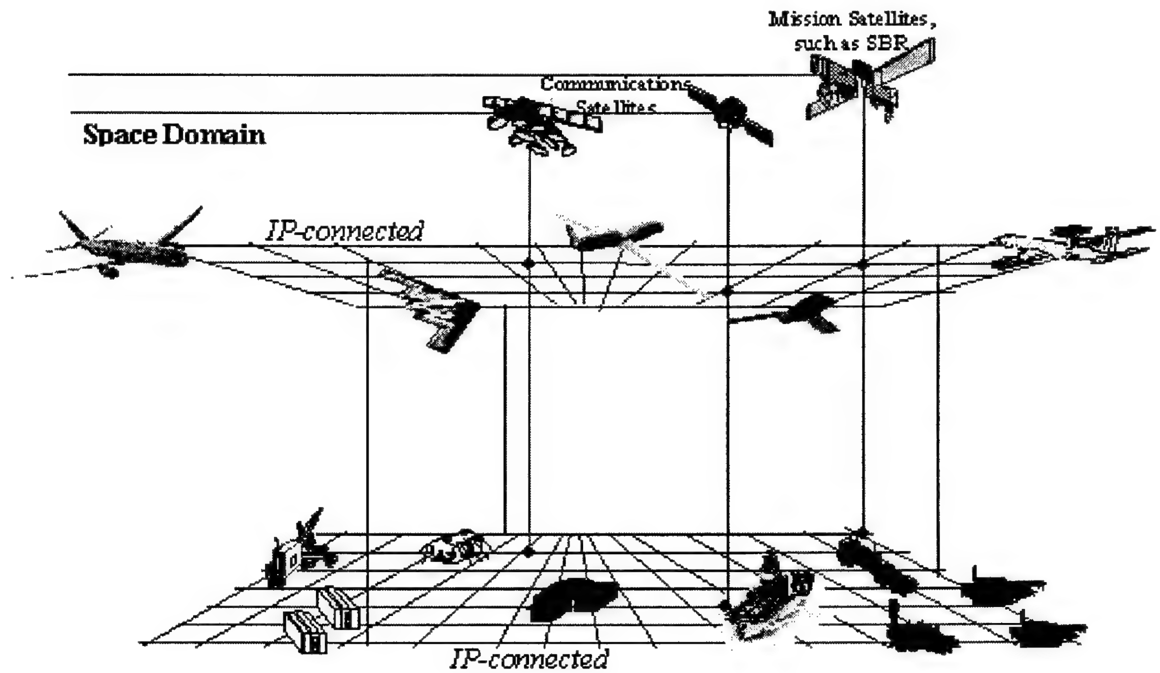

Figure 2-9 IP Network Operational View

Network operations are really nothing new to the Navy/Marine Corps. They have been operating within a networked environment for many years. FORCEnet is not network centric warfare. It is the Navy's implementation strategy for network centric warfare.

"FORCEnet is the operational construct and architectural framework for Naval Warfare in the Information Age which integrates WARRIORS, sensors, networks, command and control,

platforms and weapons into a networked, distributed combat force, scalable across the spectrum of conflict from seabed to space and sea to land".[4]

Figure 2-10 illustrates the FORCEnet strategy. In this diagram, all entities from the single Marine on the ground up to the satellites are connected to the same global information network. By having a robustly integrated/network force, information sharing is significantly improved. With information sharing, information quality and situational awareness is increased. An increased situational awareness enables all forces to work together more efficiently and effectively yielding mission success.

The current Marine Corps vision of FORCEnet has it as the glue binding sea strike, sea shield, and sea support together. Figure 2-11 illustrates how the Marine Corps envisions the FORCEnet concept. Sea strike, sea shield, and sea support are all brought together with FORCEnet under the Sea Basing umbrella. It is the component that provides the information and support for them to work together.

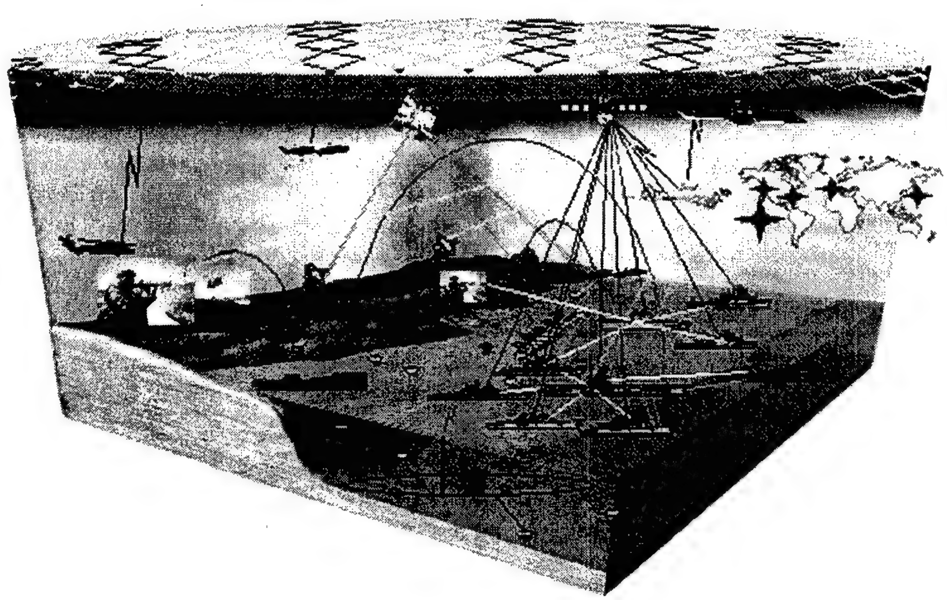

Figure 2-10 FORCEnet Concept

[4] CNO's Strategic Study Group – XXI definition from 22 July 02 CNO Briefing

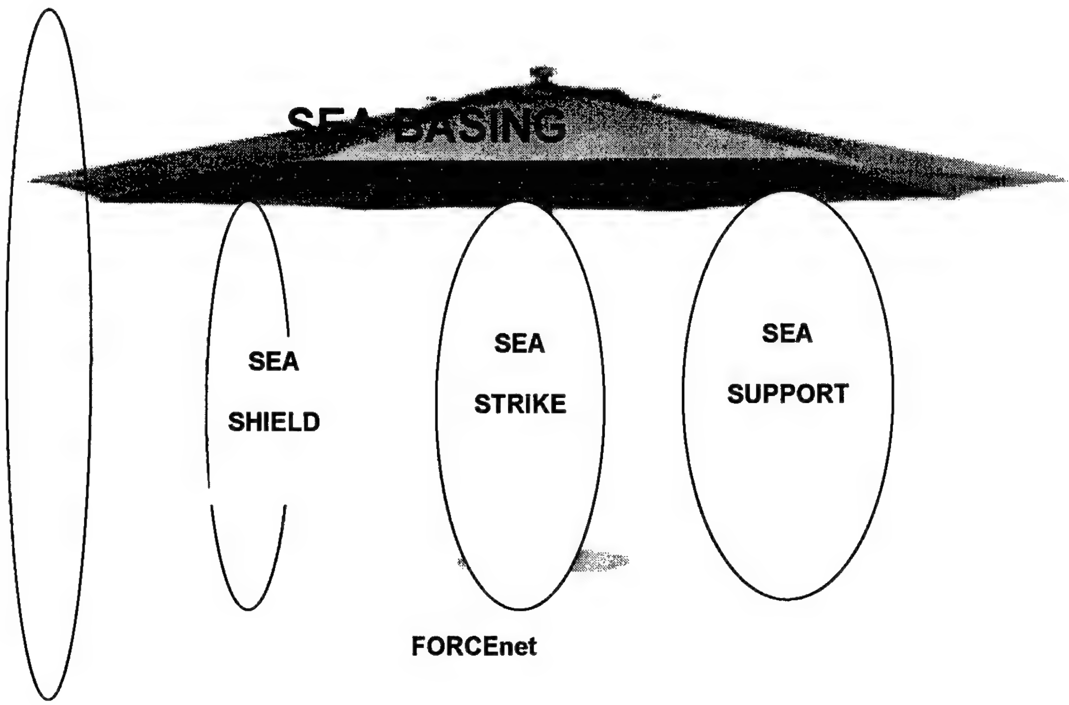

Figure 2-11 Marine Corps FORCEnet Vision

FORCEnet is being assisted by the Joint Task Force (JTF) Wide Area Relay Network (WARNET) initiative. JTF WARNET is a hardware and software architecture that ties C3 systems from all the Services together in a robust combat network. The forces of US Pacific Command were involved in developing JTF WARNET from the beginning, and they have already begun to deploy it.

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3 DEPARTMENT OF DEFENSE ARCHITECTURES

By design, any architecture being developed must be interoperable with all other architectures being developed for/by the other services. Because of this, it is prudent to consider the various architectures being developed by the various services.

Each service or in the Marine Corps case, each organization, has its primary vision of what digital method for passing commands and receiving unit reports, intelligence etc., it will rely on. The Army relies upon VMF and its Tactical Internet, the Air Force upon Link-16. The Navy uses Link 11, 16, and 22 and its Cooperative Engagement Capability (CEC). The Marine Corps Ground Combat Element (GCE) implements VMF while the Air Combat Element (ACE) implements Link 11 and 16.

3.1 Background

JCS Pub 1.0 defines interoperability as: "Ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together."

Bold, aggressive action is needed now to address the shortfalls in joint interoperability. Integration is generally considered to go beyond mere interoperability to involve some degree of functional dependence. For example, a mission planning system might rely on an external intelligence database, or an air defense system on acquisition radars. While interoperable systems can function independently, an integrated system loses significant functionality if the flow of services is interrupted.

Compatibility is something less than interoperability. It means that systems/units do not interfere with each other's functioning, but it does not imply the ability to exchange services. Interoperable systems are by necessity compatible, but the converse is not necessarily true. Mere compatibility between information systems is inadequate to enable network-centric operations because it does not facilitate information sharing.

In sum, interoperability lies in the middle of an "integration continuum" between compatibility and full integration. It is important to distinguish between these three fundamentally different concepts, and failure to do so sometimes confuses the debate over interoperability.

Interoperability is just one dimension of an operational capability, such as theater air defense. Lethality, survivability, reliability, and mission functionality also are important dimensions that must be addressed in a balanced way within the cost constraint. However, in a network-centric force, the ability to exchange information and collaborate will be the key enabler of mission functionality and combat power.

While interoperability is not free, the cost is much lower if it is designed in at the beginning of development rather than if it is forced in after the fact. Furthermore, the lack of interoperability can have a very high cost by preventing mission accomplishment.

The answer to "How much interoperability is enough" is determined by the level of information sharing and collaboration required to enable the system of systems to perform its function as defined in the applicable requirement documents.

A key concept closely related to interoperability is the Global Information Grid. The GIG is the

integrated information service that will meet the information needs of all DoD users, including warfighters, warfighting supporters, and business process users. The GIG is defined by DoD's Chief Information Officer as: "The globally interconnected, end-to-end set of information capabilities, associated processes, and personnel for collecting, processing, storing, disseminating, and managing information on demand to warfighters, policy makers, and support personnel." This "network of networks" consists of joint-use segments (e.g., the Defense Information Systems Network long-haul networks) and segments that are used primarily by a single service or agency (e.g., the Army's Tactical Internet). It extends from "desktop to cockpit," including the interface between the core "infostructure" and the user components.

3.2 Army and Air Force

The Army and the Air Force have worked hard at developing a capability to seamlessly pass mission essential data to one another. Figure 3-1 illustrates how the Army plans to pass data to the Air Force for Close Air Support (CAS) missions. Figure 3-2 illustrates the data exchanges between ground and aviation forces throughout the battlefield.

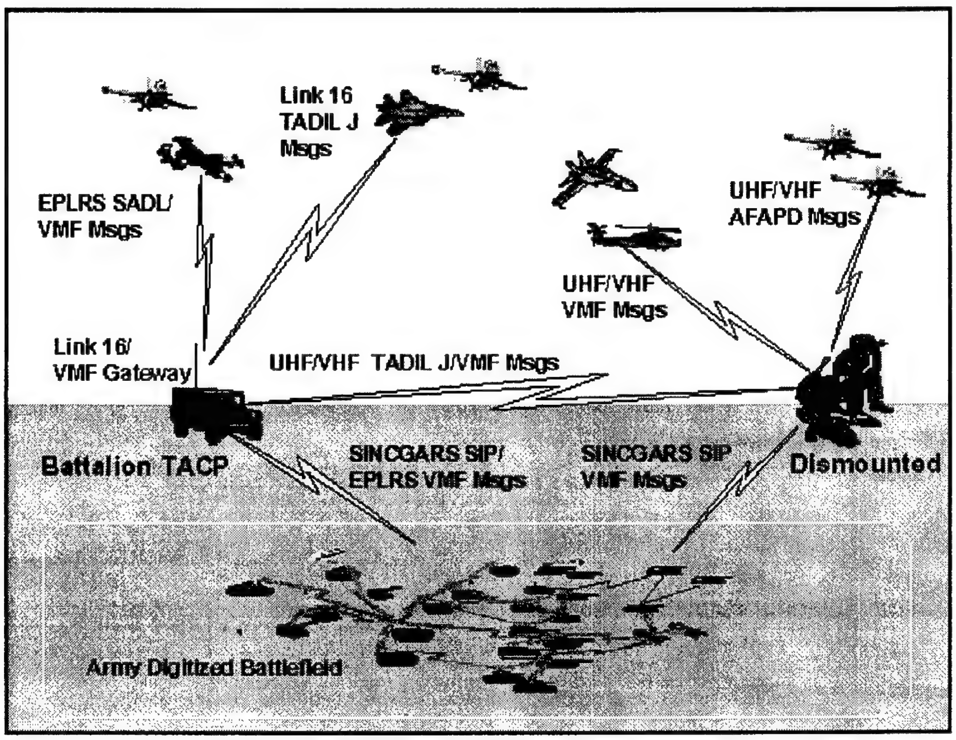

Figure 3-1 Army CAS Mission C2 Vision

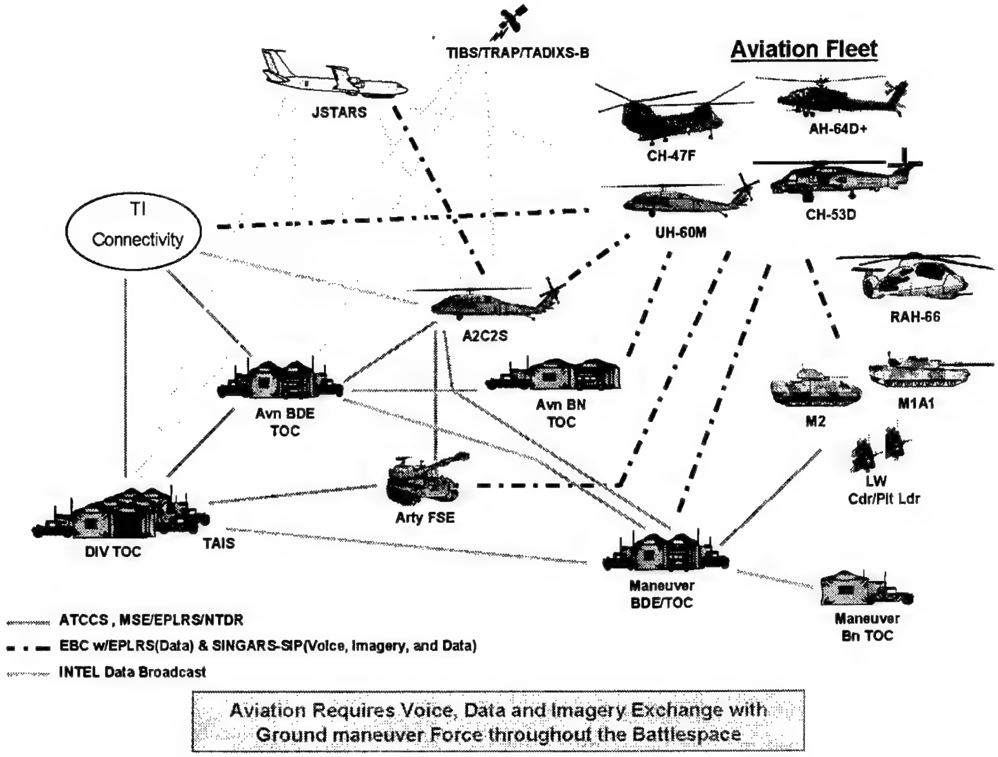

Figure 3-2 Army Data Link Architecture Vision

It is a long-term goal of the Air Force Air Request Net to use the Cluster 1 radio (including its Link-16 capability) to effect such relaying using stacked Link-16 nets. The TACP will likely have access to the Army Battle Command System (ABCS) on the Army Digitized Battlefield (ADB) through both Link-16, via an ADB gateway, and its SINCGARS radio. Either may be used to provide the friendly ground situation to the Tactical Air Control Party (TACP) for sending to the fighters on the CAS subnet. Candidate relay nodes for such information are the Air Support Operations Center (ASOC), Joint Surveillance and Target Attack Radar System (JSTARS) and/or Airborne Warning and Control System (AWACS). The Army plans to have all army units down to the platoon or lower in some cases, report their location via the ABCS. At the platoon level, the reports will go out on SINCGARS radios. At higher levels, the reports will be exchanged on the EPLRS system or in the future on another digital communications system. The TACP will be able to follow the aircraft as it approaches the target by receiving position reports transmitted on Link-16. Much of the information normally provided in the CAS check-in briefing will be available to the TACP long before the CAS aircraft reach the Control Point (CP) via status messages received from the CAS aircraft. At the so-called aircraft CP, the TACP will make voice contact with arriving CAS aircraft. Very little information needs to be passed by voice at this point because the TACP will have been in data link communication with these aircraft. This will do away with the need for the traditional CAS check-in and Nine-Line Briefings that are currently exchanged at the CP.

Once the fighters are on the CAS net of the TACP, the TACP will send updated target assignments and related mission data to the CAS aircraft on the CAS subnet. The TACP will provide:

- Target designation
- Friendly locations
- Ground threats (along with those from other sources)
- Landmarks (Contact Point and Initial Point)
- Other ground entities, e.g., civilian concentrations

in a sequence of mission assignments. The ingress and egress vectors will also be sent as part of the target assignment sequence.

Friendly troops' locations will be derived by the TACP from the ADB system, from direct observation, by monitoring the Joint Data Network (JDN) and any other resources available to the TACP. The flight leader may manually acknowledge mission assignments. Note that when the flight makes contact with the TACP, each entity the TACP has identified, e.g., target, friendly, landmark, etc., will be sent to the flight as a mission assignment. The Link 16 terminal will automatically acknowledge all mission assignment data. This in turn provides the TACP with positive confirmation that all data elements were successfully received without pilot intervention. When necessary, the TACP may require pilot acknowledgment of specific assignments. For example, if the TACP becomes aware of a friendly unit close to the target late in the mission, it may send a mission assignment requiring operator acknowledgment to the aircraft to ensure that they are aware of the friendly position before releasing weapons.

With a little effort and planning this vision of CAS can easily be merged with the Marine Corps current plans.

Another aspect of the Air Forces transformational plan that can play a significant role within the USMC is their view of Joint Fires and targeting. Figure 3-3 illustrates their vision. Utilizing airborne platforms, whether UAVs or some other platform to relay sensor data directly to a shooter, will certainly reduce the time required prosecuting a target. This concept is also being looked at by the Navy in their time sensitive strike program. This concept melds in well with the direction the Marine Corps is already heading. The only change we would make to it is in its reliance on Satellites. Other airborne assets can provide the same functionality. Details of these other platforms are outlined in the following chapters.

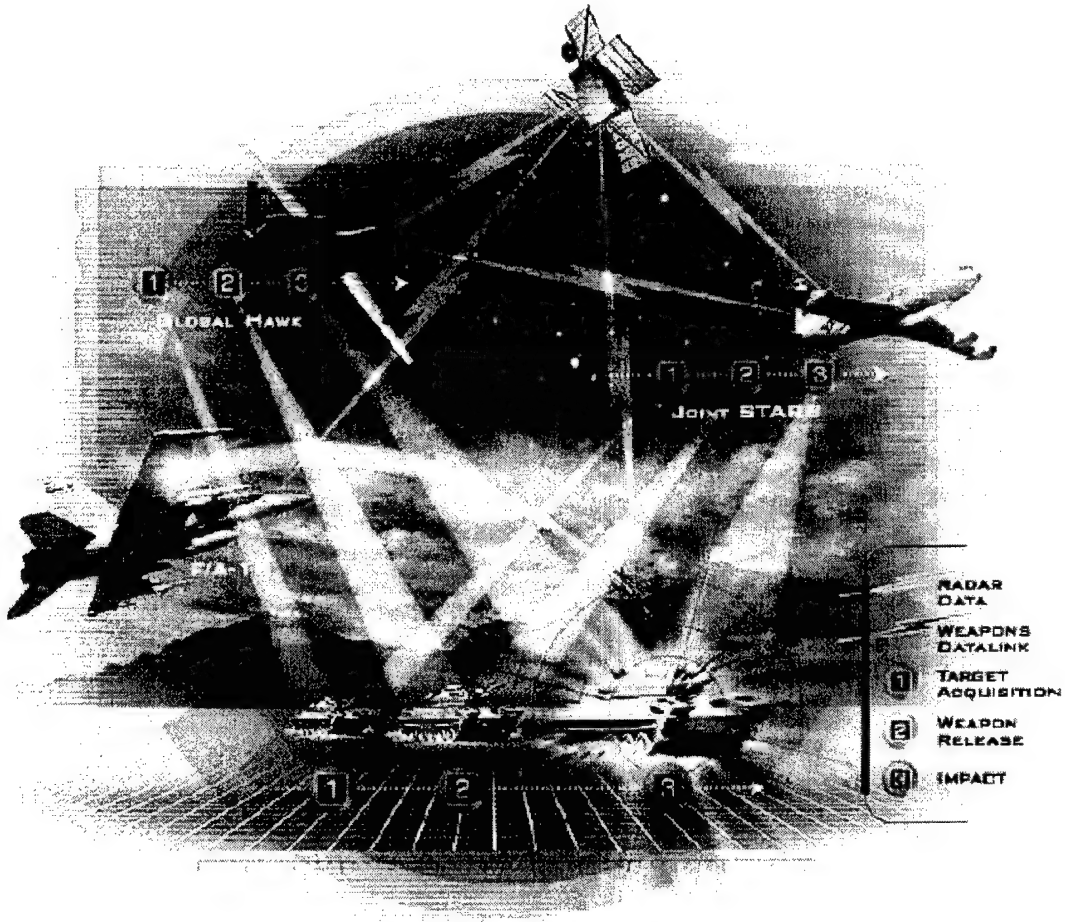

Figure 3-3 AF Netted Fires View

3.3 Navy

Figure 3-4 illustrates the C2 architecture proposed by the Navy. Note that in this architecture, the Navy has already migrated away from the legacy data links. The Navy also realizes the need for a gateway for Link 16 to Joint Variable Message Format (JVMF) translation. They are leaning toward the Rosetta algorithm. This would allow them interoperability with the Army. They also believe that Link 16 needs to become IP based or at least translatable into an IP based format. In their architecture, this would make the data available to all network participants. Hence, a user with SIPRNET access anywhere in the world could view the data link information being passed on the "local" link network. These ideas fit well with the needs of the Marine Corps.

As described in the preceding chapter, FORCEnet is the Navy's architecture of warriors, weapons, sensors, networks, decision aids and supporting systems integrated into a highly adaptive, human-centric, comprehensive maritime system that operates from seabed to space, from sea to land. By exploiting existing and emerging technologies,

FORCEnet enables dispersed, human, decision-makers to leverage military capabilities to achieve dominance across the entire mission landscape with joint, allied and coalition partners. FORCEnet is the future implementation of Network Centric Warfare in the Naval Services.

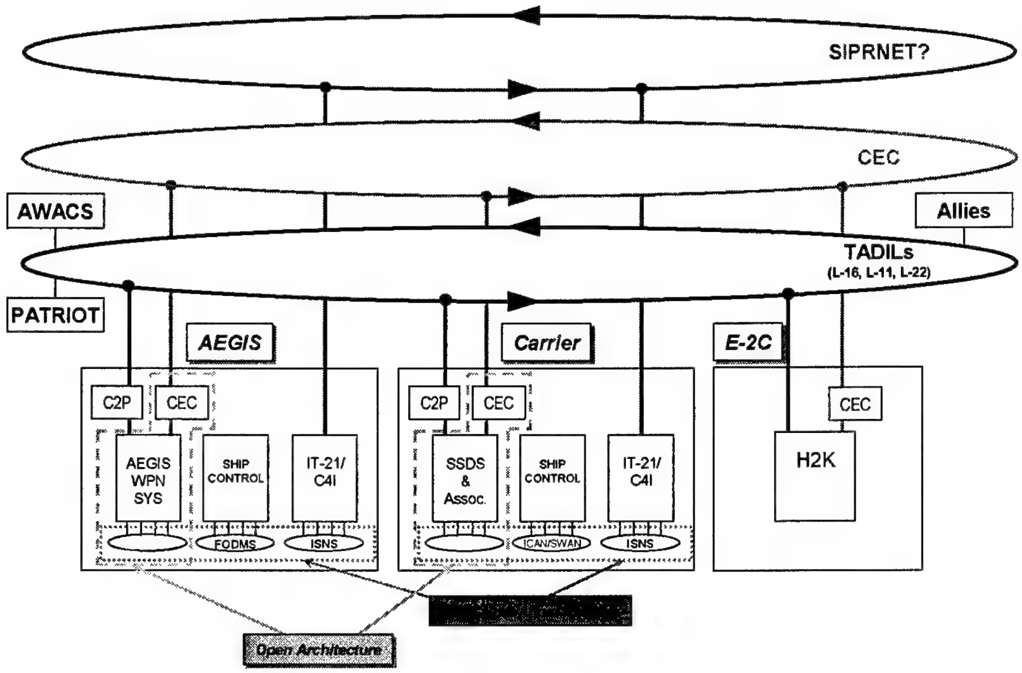

Figure 3-4 Navy C2 Architecture Vision

One approach being pursued focuses on improving battlespace awareness and reducing the time needed to carry out strikes against mobile targets by speeding the flow of information from intelligence and surveillance sensors to tactical controllers. These surveillance sensors include current theater standoff ISR platforms such as the EP-3, U-2, JSTARS and Global Hawk UAV, attack submarines on clandestine operations, or SEAL and reconnaissance teams inserted behind enemy lines. Future sensors will include systems such as the Space Based Radar, Broad Area Maritime Surveillance Unmanned Aerial Vehicles and penetrating "sensors" such as the Ground Weapons Locating Radars, Predator and Dragon Eye UAVs; and Navy Unmanned Combat Air Vehicles (UCAV-N), all interoperable with the Naval Fires Network (NFN) and Joint Fires network. Design improvements slated for the new generation aircraft carrier (CVN(X)) will facilitate the ability to introduce UAVs and UCAVs into the battleforce of the future. [5]

[5] Naval Transformation Roadmap

3.4 Air Force, Army and Navy

The traditional approach to TDL integration has been to develop a customized implementation for each individual platform that is embedded within an onboard mission computer. Host platform integration has consistently been the greatest challenge for platforms requiring a TDL capability, particularly in the advanced and complex arena of Link-16 communications. There have been exceptions to this approach. For example, on US Navy Ships, a significant amount of platform TDL message processing and integration occurs in the Command & Control Processor (C2P). Reducing cost and risk, while achieving commonality in implementation, provides the incentive to seek an integration solution that segregates the TDL processing functionality in a Common TDL Processing application or module.

The Air Force Tactical Links International Program Office/PEO (C4I) has teamed with the Air Force Tactical Data Link System Program Office (TDL SPO), the Army PEO (Aviation), the Navy Common Avionics Program Office (PMA 209) of the Naval Air Systems Command (NAVAIR) to form an Integrated Product Team. They are currently seeking information pertaining to a possible future procurement and/or development of a joint service, cross-platform, TDL message processing and integration application for use in a variety of military platforms and installations, including (but not limited to) aircraft, ships, command & control shore sites, and ground based tactical units.

This Joint Navy/Air Force/Army initiative, originally titled Low Cost Integration (LCI), is in its final investigative and planning phase. The program is now called Common Link Integration Processing (CLIP). CLIP is envisioned to be a common software solution that will provide a range of TDL functions that are tailorable to individual platforms needs, capable of being hosted in a range of architectures. It is intended that this capability isolate the platform mission computer/combat system from the many changes that occur with TDL evolution thereby facilitating the incorporation of changes to existing TDL standards without impacting the host platform systems. This will be an evolutionary spiral development process with functionality specified at each delivery point to match platform TDL requirements.

The CLIP program is in its infancy. Marine Corps would benefit by joining the program. Several of the issues identified with TDL interoperability are being addressed by this program.

3.5 Current Marine Corps Plans

Figure 3-5 illustrates the top-level view of the OMFTS C4ISR systems architecture. The architecture consists of a large number of low-power wireless local area networks (WLANs) interconnected by a self-organizing wide area network (WAN) JTRS radios. To prevent fragmentation of the network due to distance or terrain, airborne relay nodes are required to augment the terrestrial portion of the WAN backbone. Similarly, broadband and satellite communications terminals supplement the JTRS network where ranges are extended or heavy traffic concentrations are likely.

An important aspect of this architecture is that all classes and classifications of traffic share the same network backbone. In other words, voice, video, and data share the same switching and transmission systems, regardless of their level of classification (e.g., secret or unclassified). However, selected niche systems; such as remote sensors, deep reconnaissance teams, and high bandwidth sensors (e.g., synthetic aperture radars); will require special-purpose links from terminal systems to processing stations, where data is processed before further distribution via the common network.

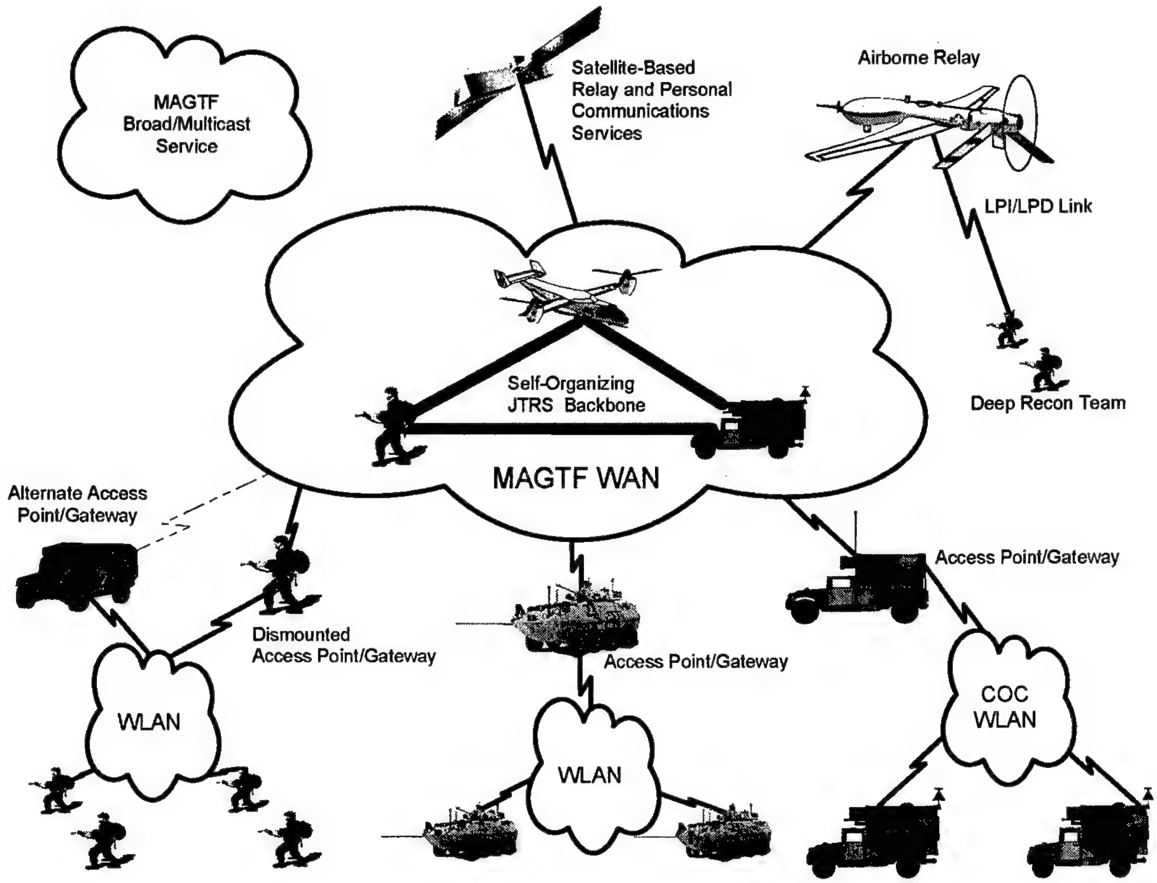

Figure 3-5 Marine Corps JTRS WNW Architecture Vision

Figure 3-6 illustrates the overall C2 architecture. Note that the Marine Corps architecture is similar to the Navy architecture in that they both have a gateway to translate between Link-16 (J-series messages) and JVMF, which is IP based.

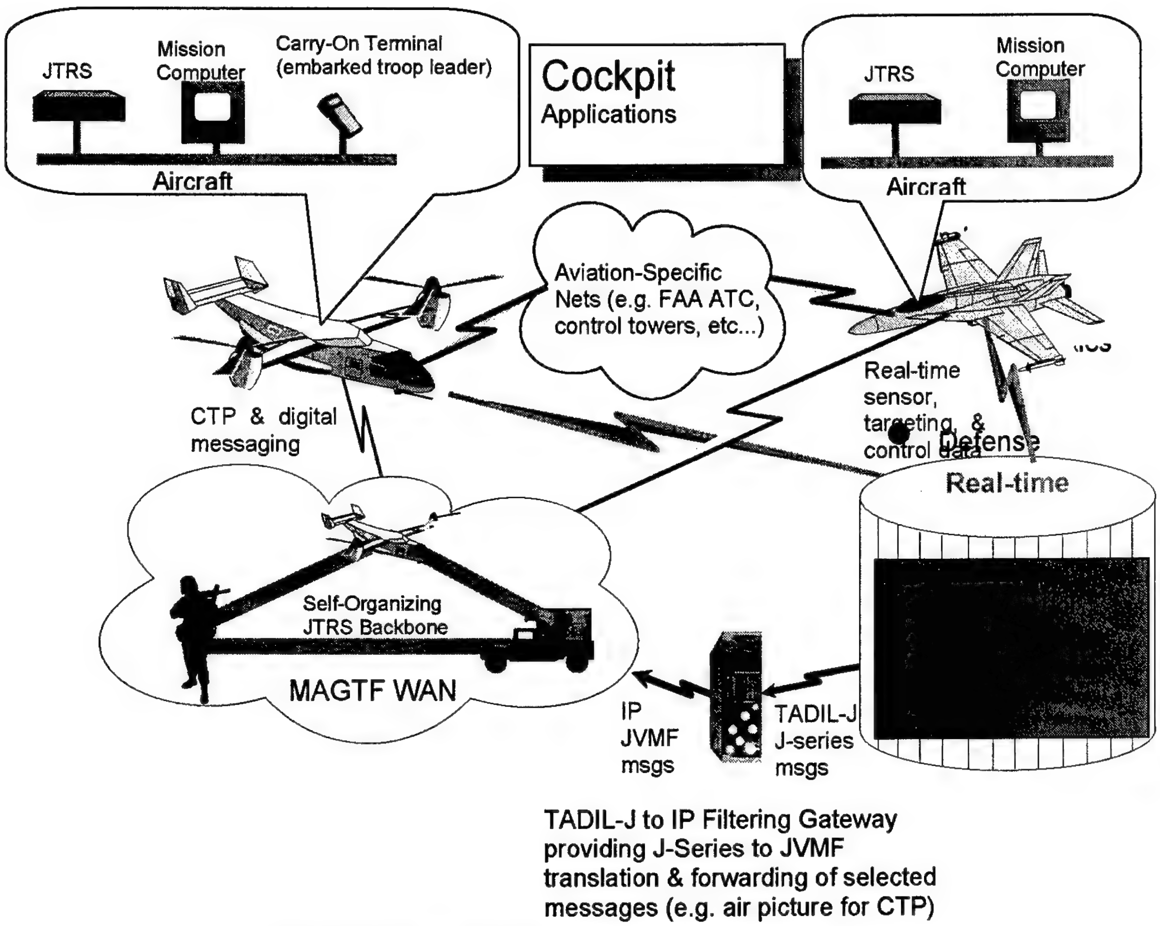

Figure 3-6 Marine Corps Architecture Vision

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4 BEYOND LINE OF SIGHT CONCEPT OF OPERATIONS

The Littoral Combat Future Naval Capabilities sponsored a war game during 1-4 April 2002. The purpose of the war game was to provide analytical rigor for the development of a Science and Technology Investment Plan. At the end of the session, priority shortfalls were identified. The number one priority shortfall from a C2 viewpoint was the lack of sufficient BLOS communications capabilities.

The above example is just one of many documented instances where insufficient BLOS communication capabilities has been identified as a short fall. Unless the Marine Corps addresses this issue, STOM will be severely hindered. The intent of this chapter is to outline a CONOPS that will provide STOM with adequate BLOS assets.

4.1 Introduction

4.1.1 Scope

This CONOPS describes the communications layers and communications assets as they relate to the STOM. It proposes an architecture that implements terrestrial, airborne, and spaceborne systems designed to provide the communications infrastructure required by the Marine Corps. Additionally, interrelationships between combat zones and spatial layers are outlined.

4.1.2 Purpose

This section of the COLE is provided in order to define the communications framework required to accomplish the Marine Corps STOM mission. Through this definition, the intent is to emphasize the need for a multi-layered (multizone), redundant network of communications systems. While this document may stand alone, it is more specifically designed as a supplement to the COLE as it addresses the entire MACCS family of systems.

4.1.3 Definitions

Prior to establishing a CONOPS, an understanding of the communications problem is required. The purpose of this section is to establish the terminology used throughout the remaining sections.

4.1.3.1 Line of Sight

Currently, the primary means of communications for the Marine Corps in a tactical environment are Very-High Frequency (VHF) and Ultra-High Frequency (UHF) band radios. These radios typically communicate via LOS. LOS implies that both transmit and receive antennas are located within a straight, somewhat unobstructed path from each other. In many cases, this maximum distance is estimated to be 25 miles. Figure 4-1 illustrates a basic model for LOS communication. To calculate the total reachable distance for two antennas, you must take the sum of the two radio horizon distances (D1 and D2).

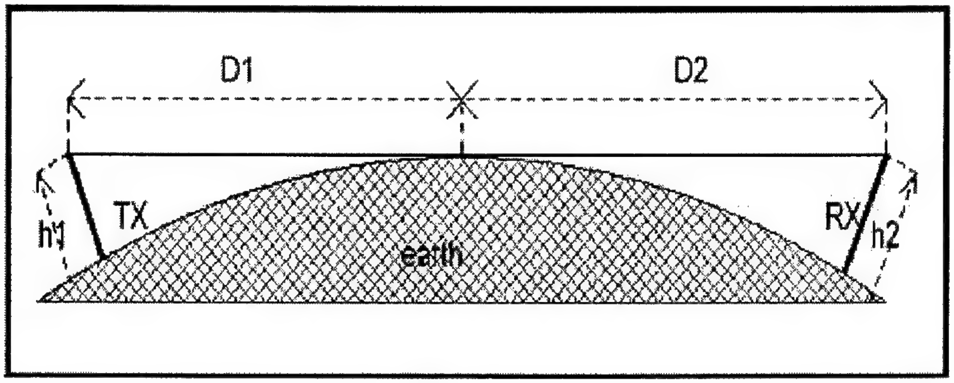

Figure 4-1 LOS Illustration

Based on Figure 4-1, one would expect a strong relationship between LOS distance and antenna heights. Figure 4-2 illustrates the required antenna heights for a given LOS distance. For example, assume a requirement exists to communicate via LOS means a distance of 20 miles. From Figure 4-2, one can determine that the transmit and receive antennae must be located at least 200 feet above the ground. Note that this assumes ideal geometry and propagation conditions.

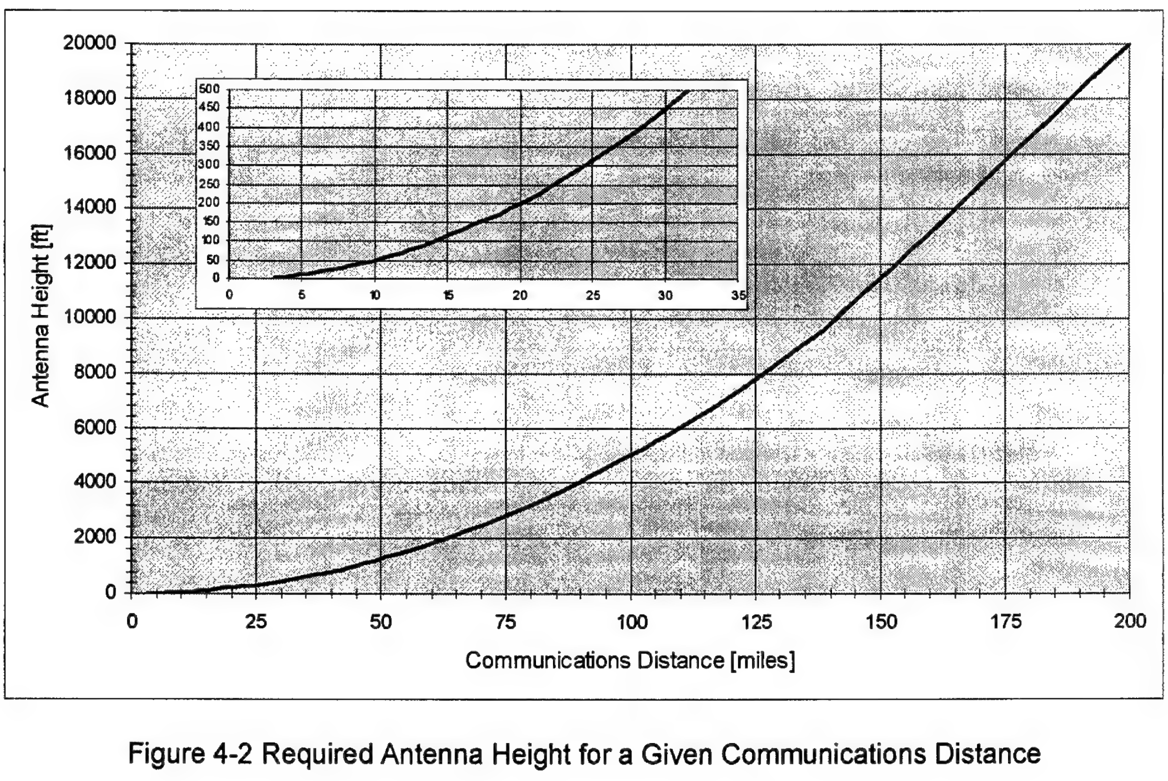

Figure 4-2 Required Antenna Height for a Given Communications Distance

Radio waves typically only travel a true straight line in a vacuum. In a real world environment, all waves experience refraction. Refraction is the bending of a wave as it passes through dissimilar media. As a signal travels through the atmosphere, it will pass through areas of different temperatures, pressures, and densities. These changes in the atmosphere will cause the signal to bend either toward or away from the earth's surface. This can cause a deviation in the distance the signal travels. In rare situations, a phenomenon known as ducting can occur. Ducting takes place when a signal is trapped in a channel of the atmosphere due to a temperature inversion. This can cause a VHF signal to travel well past LOS. In addition to diffraction and refraction, a signal can also encounter scattering as they travel through the troposphere. Tropospheric scattering (a.k.a. troposcatter) occurs when a signal is dispersed as it passes through layers of varying indices of refraction. This effect is similar to ducting in that it also can cause a signal to propagate well over the horizon.

4.1.3.2 Beyond Line of Sight

Once the direct path between two antennas falls below the curvature of the earth, communication at VHF and above frequencies becomes extremely difficult to achieve. To negotiate this problem in the past, frequencies were lowered (HF band).

Lowering the frequency increases the wavelength of the signal. These signals, such as HF signals, are able to reach distances well past LOS. This is because the atmosphere, especially the troposphere, affects lower frequency signals more, i.e., it bends the signal back towards the earth. However, lowering the frequency comes with a price. Data rates, i.e., the rate at which data can be placed on a transmission, are also lowered. With the volume of information to be sent in the future, this is no longer a viable option. Currently, the best solution is using some type of relay to connect two signals that are BLOS.

Figure 4-3 illustrates the position in space where a relay would be required for two points located below the horizon to communicate. Simply put, the relay must be within LOS distances of both the transmitter and receiver for communications to occur.

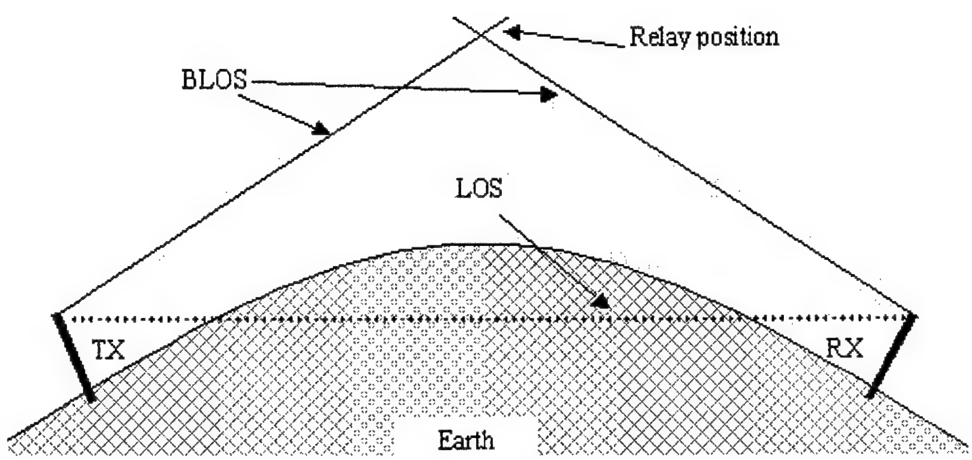

Figure 4-3 Relay Position Geometry

Note that the previous figure is a trivial example. Many other configurations/options to BLOS communications exist. The distance between the two antennas will determine whether the relay needs to be on the ground, in the air, or in space. Figure 4-4 illustrates how different types of BLOS communication relays can be used for varying distances. By using a zonal approach, the types of relays required will be able to be categorized by the distances they must travel.

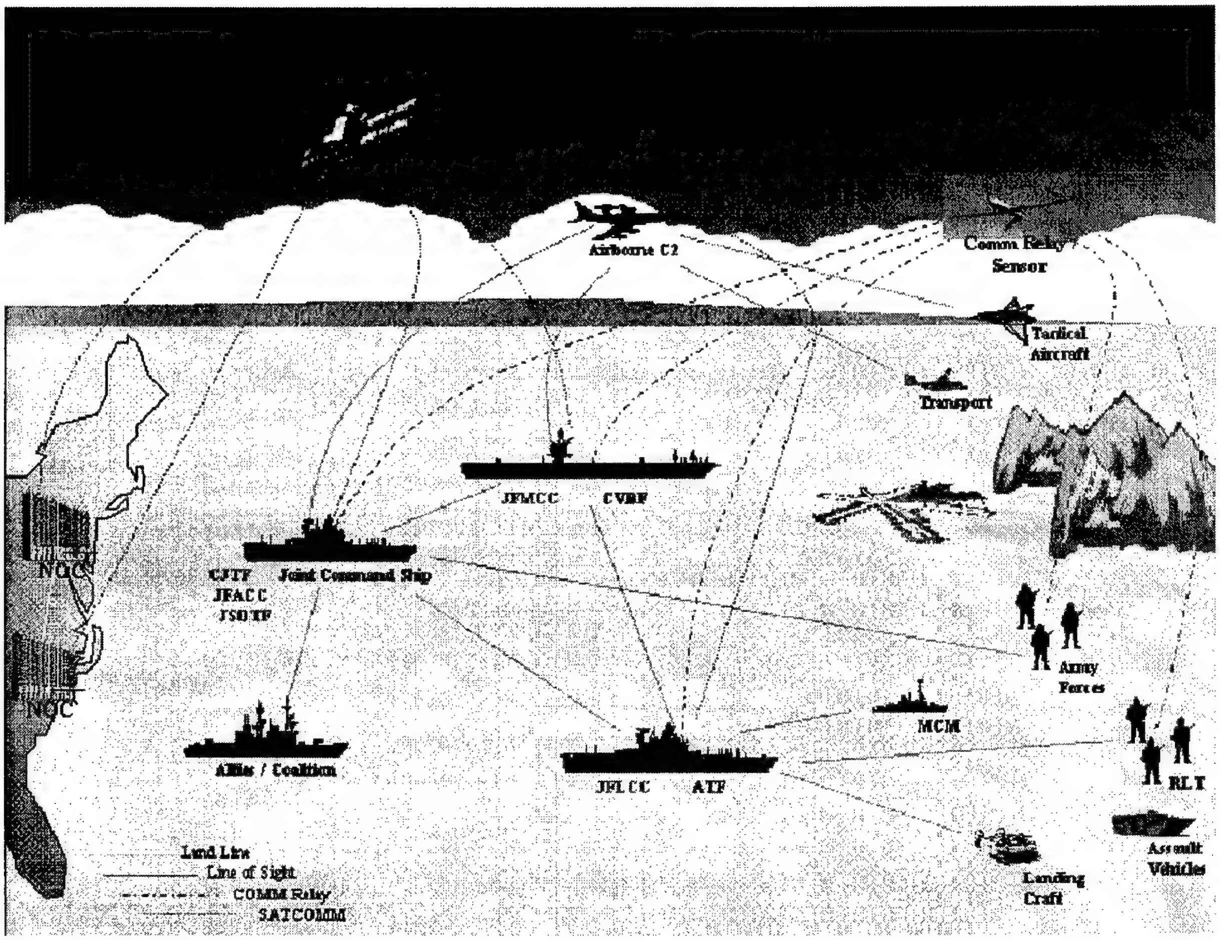

Figure 4-4 Communications Relay Illustration

From the figure, one can see that a satellite can link CONUS to region of conflict while an airborne platform can only link between sea based platforms and some ashore assets.

One problem with the above figure lies in the fact that the terrain is basically flat. Hence, it appears that a single relay might be sufficient to solve the long haul communications problem. This is not always the case. The look angle to an asset becomes very important. This is especially true in an urban canyon or mountainous terrain.

4.1.3.3 Communication Physics

Besides propagation, numerous other phenomena dictate the distance a signal travels as well as how much information can be carried. For the purposes of this study, frequency and bandwidth are two topics of great importance. Their significance lies in not only their necessity and availability, but also their relationship with each other.

Frequency, by definition, is the number of cycles a wave travels in one second. By increasing or decreasing the amount of cycles, the signal's wavelength either shortens or lengthens, respectfully. Longer wavelengths (lower frequencies) have the ability to travel distances in the thousands of miles, while shorter wavelengths (higher frequencies) cannot usually travel in excess of 100 miles. These distances can fluctuate depending on transmit power, geography, and the effects of propagation.

Frequency, by application, is a specific location along the electromagnetic spectrum. The frequency that is selected on a radio is approximately located at the peak of that signal, known as the carrier frequency. An analog signal travels in a sinusoidal pattern. Because of this sinusoidal pattern, the signal will also have a high and low frequency. The signal's bandwidth is the available distance between its high and low frequency. This is typically -3 dB below the carrier frequency. A frequency's bandwidth regulates the amount of information that can be transmitted and received on a given band. This is shown graphically in Figure 4-5 below.

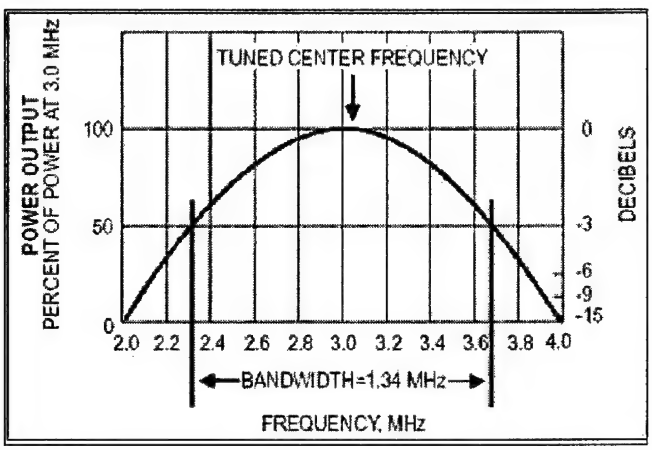

Figure 4-5 Bandwidth of a Frequency

Bandwidth is and will be the main limiting factor in data communications. As the volume of transmitted data becomes larger and more complex, the required bandwidth will also increase. Figure 4-6 illustrates typical bandwidths at various band segments used by the military. Generally, the more bandwidth needed the higher the required frequency. This can cause complications because higher frequencies tend to travel shorter distances and are affected more by propagation effects.

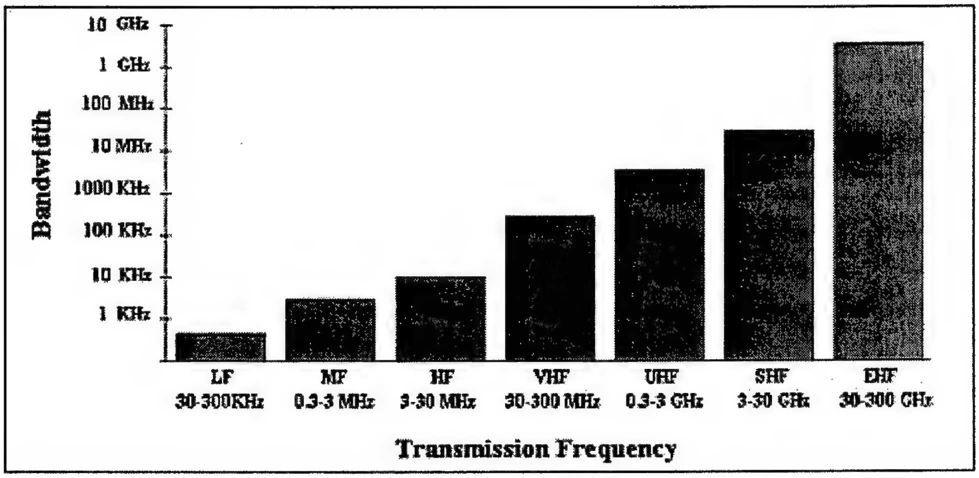

Figure 4-6 Theoretical Bandwidths for Various Military RF Bands

4.1.4 Communications and Information Architecture

Because of the complexity of any comprehensive BLOS communications system, no single, all encompassing region can be defined. The optimal communications and information architecture is one that encompasses both terrestrial regions or zones and airborne layers or tiers. The terrestrial regions are defined similar to the regions of conflict, i.e., distance from "center" point while the airborne layers are based upon altitude. Network components in each zone/layer will be interconnected with those in the other mutually supporting layers to form a survivable and dependable communications backbone. These systems (both software-driven and traditional "human-driven") together will enable a self-configuring, self-healing, dynamic BLOS communication network. When fully functional, the architecture should support a deployed force continuously, i.e., 24-hours-a-day, seven-days-a-week, anywhere in the world and under any weather and terrain conditions.

4.1.4.1 Terrestrial Zones

The terrestrial zones, shown in Figure 4-7 are: Inter-Zone, Reach-Back/Reach-Forward, and Intra-Zone. These zones are categorized by the distance between transmit and receive antennas. The Intra-Zone is comprised of, in most cases, the battlefield (tactical) area. This zone will focus mostly on inter/intra-unit voice communication, e.g., between two vehicles in a convoy or to a vehicle from a different unit. The majority of the communications in this zone will be comprised of LOS; however, in future scenarios, some units will advance farther away from command posts making BLOS communications more common. In the incidences when BLOS communication is needed, a low-altitude airborne relay should be sufficient.

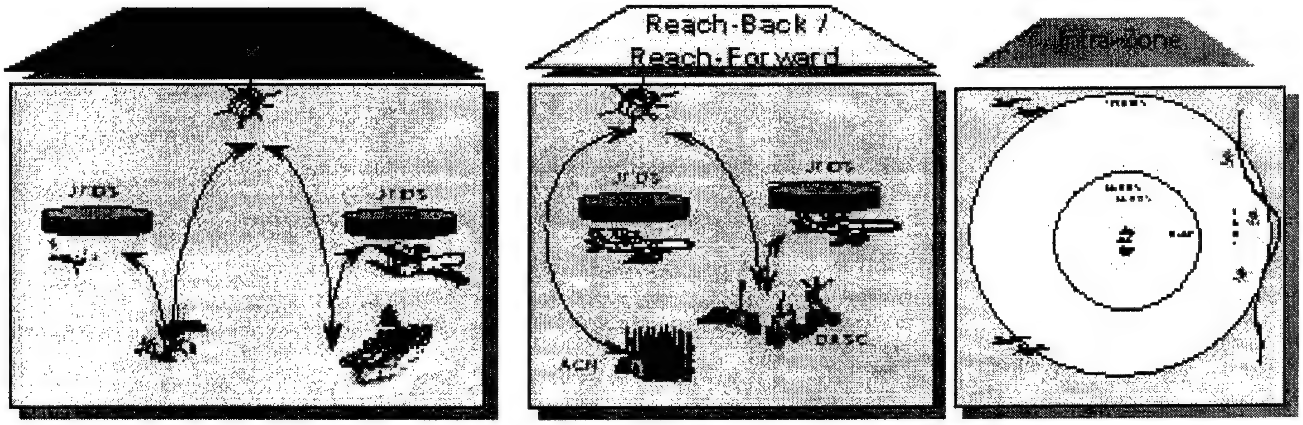

Figure 4-7 BLOS Zonal Areas

The Inter-Zone envelops several intra-zones within a theater network as well as battle groups offshore and localized aircraft. LOS will rarely be able to be used in this zone. This zone will also most likely need to contain a communication link capable of sending and receiving large data transmissions. Voice signals would also be utilized within the Inter-Zone, although data links will begin to phase voice out at these distances. High-altitude airborne relays or low orbit satellites may be required to link signals this far beyond LOS.

Reach-Back and Reach-Forward zones will almost exclusively use satellite communication. These zones will connect battle groups to CONUS and aircraft in transit to a theater network.

4.1.4.2 Layer Approach

To solve the BLOS problem, relay assets must be placed at various altitudes. Figure 4-8 illustrates an additional three layers based upon altitude. The layers have been identified as: terrestrial, airborne and spaceborne.

4.1.4.2.1 Terrestrial Layer

The terrestrial or ground communications layer interconnects ground based assets and is critical for interconnecting highly mobile tactical elements. LOS wireless links interconnect dispersed tactical elements. These links are extended by the automatic routing capability of JTRS radios and linkage with the airborne and spaceborne systems.

The network should be self-configuring and self-healing. The assets should be embedded in the warfighting as well as the C2 platforms deployed in the battlefield. Assuming these statements true, a terrestrial layer provides:

- Demand on airborne and spaceborne assets is reduced. A message is passed BLOS via a series of LOS hops.

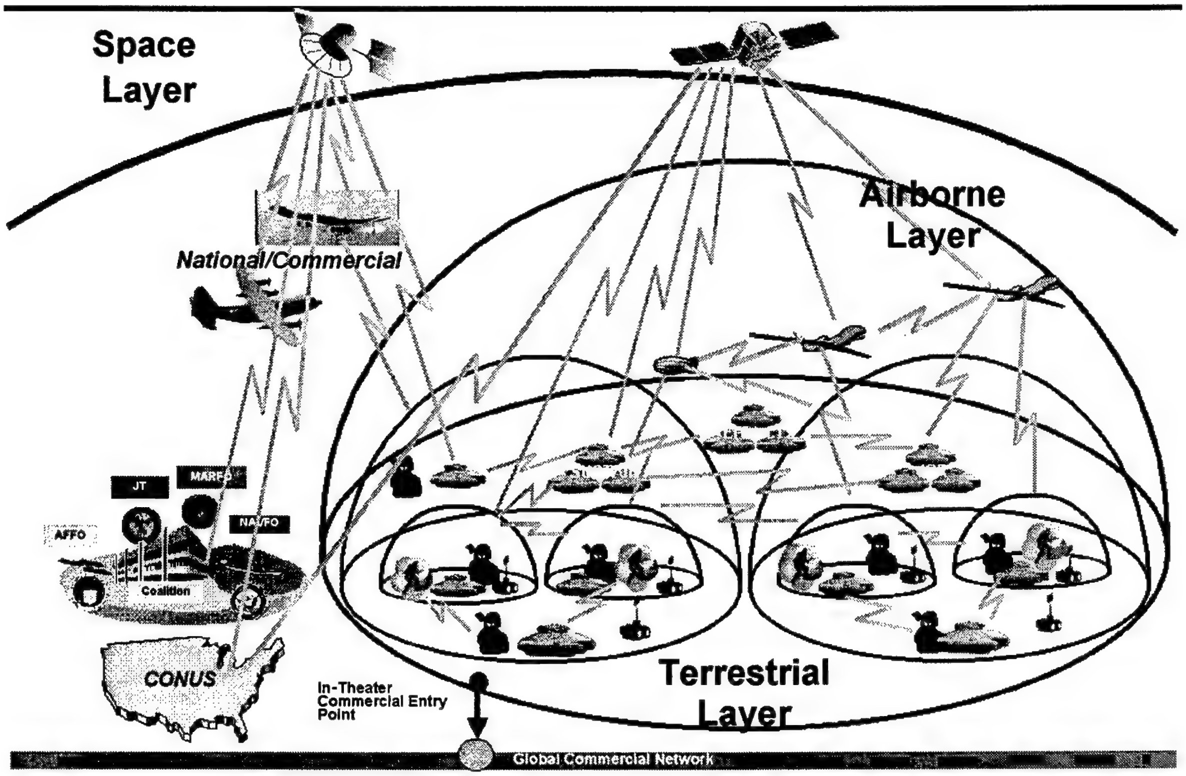

Figure 4-8 Multi-layered Communication Network

- Network traffic has alternate routing paths. This in turn contributes to network reliability, i.e., a data packet can get to its destination via multiple paths.

- Enhanced low probability of intercept/detection communications is provided. Hops are LOS therefore minimal transmitter power is required.

- Increased troop security. The terrestrial layer complicates an adversary's counter-C4 effort (must target multiple layers-terrestrial, airborne and space). This also improves network durability and reliability.

- Assets used to create the BLOS network can be organic to the force implementing the communications network.

Drawbacks of the terrestrial layer also exist. Most important is that eventually one asset will be required to "sit" on the high ground. Without this high asset the BLOS problem still exists. A second drawback is in the architecture itself. The BLOS problem is addressed with an extended series of LOS links. The number of links required to cover several hundred miles is significant. Note that for a short BLOS problem, this is not as significant an issue.

4.1.4.2.2 Airborne Layer

The airborne communications layer contains manned and unmanned aerial vehicles carrying communications payloads (relays) at a variety of altitudes. Table 4-1 provides definitions for various altitudes and gives examples of what assets may be available at the given altitude.

Table 4-1 Airborne Layer Definitions

	Altitude (ft)	Examples
Very low	< 1000	Tactical UAVs, tethered dirigibles
Low	1000 - 10000	UAVs, rotary wing assets, tethered dirigibles
Medium	10000-30000	UAVs, rotary and fixed wing air assets
High	30000-60000	UAVs, manned, fixed wing, air assets, untethered dirigibles,
Low space	>60000	Large UAVs, untethered dirigibles

Notice that virtually all aircraft that carry a JTRS or a variant of JTRS can function as a relay in this architecture. Figure 4-9 illustrates a typical airborne relay scenario. The slant range of 85 miles is typical between an airborne asset at cruising altitude and a ground element. Slant ranges greater than 100 miles are possible between two airborne systems. Actual range will be a function of the two platforms altitude.

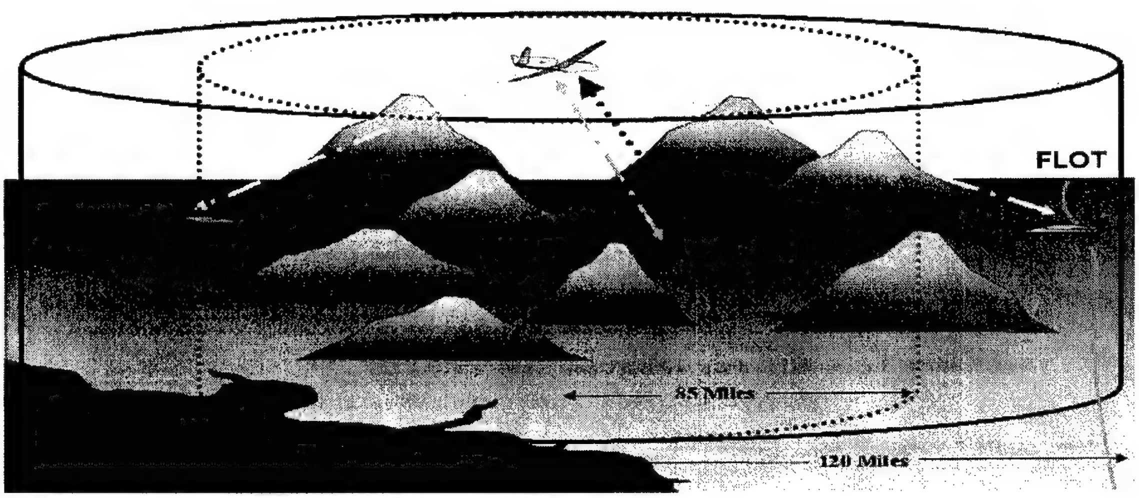

Figure 4-9 Airborne relay illustration

Tactical relays, i.e., those assets controlled by C2 personnel, will be carried at low altitude on UAV platforms. At medium and high altitudes, larger, longer range systems will be deployed to provide required coverage. High altitude assets will include the larger UAVs and low space, High Altitude Platforms. The assets in this layer route traffic via all available links. They can pass traffic to other airborne relays, spaceborne systems or even to terrestrial assets.

An airborne communications layer has several advantages. These include:

- When high-altitude, long-range UAVs are employed, they can be pre positioned to support deploying forces.
- Airborne assets act as surrogate satellites reducing SATCOM traffic load.
- Airborne assets being closer to the ground than satellites require less transmitter power. This decreases their probability of being intercepted/detected.
- Unlike satellite systems, an airborne relay's coverage area can be adjusted as needed.
- Fundamental advantage to an airborne platform is in their versatility. These systems are quite easy to move, position, and to change their payload configurations.

The airborne layer's drawbacks are focused on C2 issues. UAVs place additional and sometimes significant demands on airspace and frequency management systems. Management of the communications network will be required in order to reduce unnecessary duplication of coverage for the airborne assets.

Other disadvantages revolve around the fact that these systems are airborne. First, airborne operations may be affected by weather conditions. Low and medium altitude assets will typically be operating over hostile territory. These assets could be subject to enemy attack/denial of service.

4.1.4.2.3 Space Borne Layer

The space layer includes military and commercial satellites. These satellites have dedicated communications relay payloads. Like the airborne systems, they have the ability to route traffic between all three layers.

Space based communications primarily support global operations. The platforms are always in position to support rapid deployment. The systems provide en route and on-the-move coverage. Bases located in theater as well as CONUS C2 centers have the ability to communicate with battlefield C2 centers.

While satellite systems can provide full BLOS coverage, they still have disadvantages. Unlike assets in the previous two layers, space based systems most likely will not be organic to the Marine Corps. The primary disadvantage is in available bandwidth. Commercial SATCOM systems have available bandwidth; however, the available time slots may not be optimal and, if suitable time slots are available, the cost of these slots is significant and may even be prohibitive. Military SATCOM systems are severely over subscribed.

Other disadvantages include:

- With the possible exception of CANSATS (discussed below), satellites will be a target for enemy attacks.

- Satellites have a fixed coverage footprint. Data transfer will not happen if either side is located outside of the coverage area.

- Satellite communications occur in the SHF/EHF bands. Signals in these bands can be affected by weather and obscurants.

- SATCOM on the move, using small mobile antennae can be difficult, and, when possible, offers limited bandwidth.

- SATCOM communications requires LOS communications. In many areas, satellites are low to the horizon. Even small obstructions will block the signal. It is extremely difficult with a canopy overhead. A relay would be required to get communications from the jungle floor to the canopy surface.

- Satellites have limited coverage area. Figure 4-10 illustrates how much of the Earth's surface is covered by an orbiting platform. Low Earth Orbit (LEO) systems are the cheapest to launch and operate. As one can see from the figure below, many satellites would be required to achieve reasonable coverage.

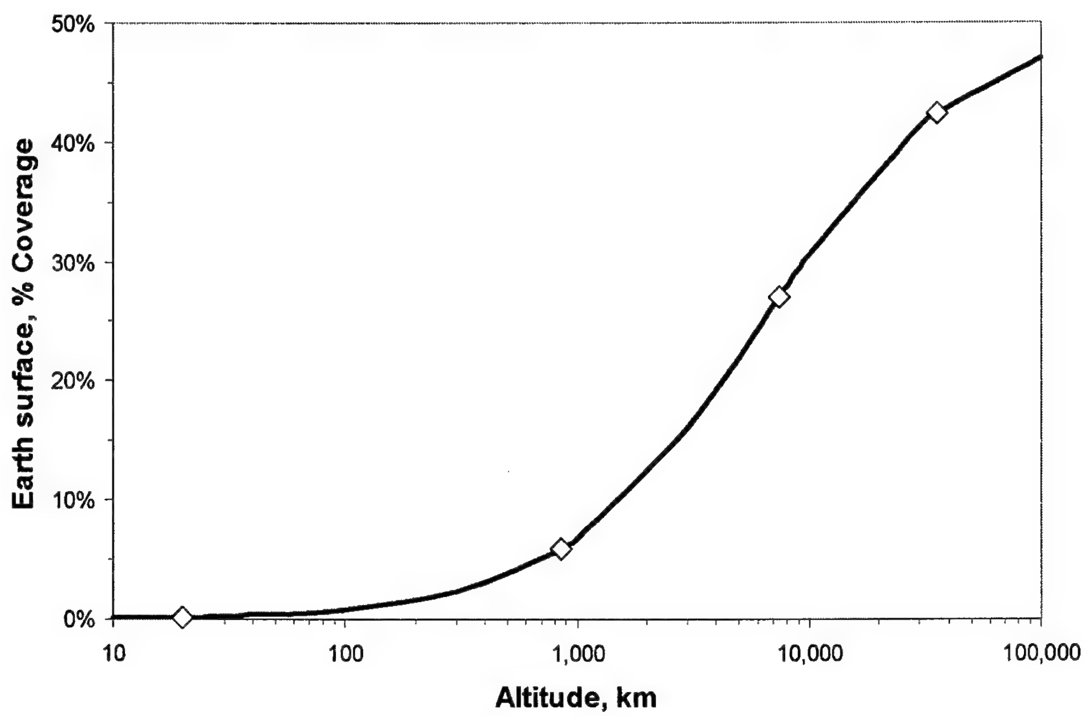

Figure 4-10 Percent of Earth's surface covered by a satellite at various altitudes

4.2 Beyond Line of Sight Asset Descriptions

Many types of platforms can be used to enable BLOS communications. These platforms range from terrestrial systems up to and including space based systems. Naturally, operating costs of each system increases as one progresses from terrestrial systems to space based systems. The intent of this section is to provide a brief background of the various systems that could be implemented in the different layers/zones.

4.2.1 Elements of the Terrestrial Layer

The terrestrial layer consists of deployable, reliable communications systems at or near ground level. Systems employed in this layer could be dedicated relay shelters, vehicles loaded with a relay payload, or even individual personnel equipped with radio relay systems.

The overall objective of the terrestrial layer is to provide assured communications between the individual combatants back to the tactical commanders. This is accomplished through a network of modular communications systems aboard platforms at the tactical levels. This architecture provides overlapping and BLOS communications ability with linkage to the airborne and space based networks.

The priority of this range extension capability is to help support Situational Awareness (SA), C2, and tactical communications. This BLOS capability helps extend the local tactical internet and to provide voice communications to/from isolated enclaves and other joint/coalition forces over the horizon.

4.2.1.1 Mobile Network Multiple-Input, Multiple-Output

Cellular networks currently dominate mobile wireless applications. In some environments though, especially the wireless battlefield context, the notion of having base stations and mobile units does not make sense. In situations where the networks are constructed and destructed in an ad hoc manner, it may make sense to have flexible ad hoc networks.

Multiple-Input, Multiple Output (MIMO) communication systems have the potential to increase channel capacity 10-20 times in the spectrum limited JTRS bands under dynamic urban near-line-of-sight multipath channel conditions where conventional single-input, single-output techniques degrade. MIMO uses multipath to create parallel channels in the same band.

4.2.1.2 Wideband Network Waveform for JTRS

The JTRS WNW network shall provide connectivity in an operational area through self-forming, self-healing mobile ad hoc networking (Figure 4-11). The JTRS WNW network shall support worldwide connectivity by inter-networking with IP-based networks on other media. The WNW network shall provide routing and management protocols/schemes that can rapidly respond to ad hoc changes in network topology caused by such things as node addition and deletion, node movements, antenna shadowing or orientation, terrain masking, or interference. Given that JTRS radios are scheduled for deployment in all assets, this concept will also be available to the airborne assets as well.

(zone) architecture provides overlapping and BLOS communications ability with linkage to the terrestrial and space based networks.

The priority of this range extension capability is to help support SA and C2. This BLOS capability helps extend the local tactical internet and to provide voice communications to isolated enclaves, deep operations and other joint/coalition forces.

4.2.2.1 High Altitude Platform Systems

High Altitude Platform Systems (HAPS) are a new emerging telecommunication platform that will be located at 20 km height in the stratosphere. They have attracted a lot of interest lately as a means of deploying telecommunication services at relatively low cost.

The cost of conventional satellites themselves, the launch costs involved and the tight satellite link budget let some telecommunications companies looking to get their payloads positioned closer and cheaper to the earth. HAPS are intended to operate over regions at an altitude of 3 km to 22 km. The equation below can be used to provide the coverage area for a given altitude (h).

$$d = 2R \cdot \left(\arccos\left(\frac{R}{R+h} \cdot \cos(\gamma) \right) - \gamma \right)$$

where R is the Earth radius (6'378 km),
γ the minimum elevation angle and h the altitude

Two concepts of stations are prevalent: balloons and aircraft. The first are unmanned, the latter are developed for manned and unmanned operation. Interest was mainly taken in balloon systems, lighter than air and heavier than air types. The airship is expected to stay aloft for several months or even years. Tethered balloons are another option; though often thought to be impractical due to the length of the tether line and the possible interference with air traffic. The second type of HAPS is an aircraft circling at 20 km height. In manned operation, several planes will operate in up to 12-hour shifts. In unmanned operation, one plane could remain aloft for months at a time.

4.2.2.1.1 Stationary Lighter than Air Platform

The Marine Corps has plans to deploy a lighter than air platform as an organic means to relay critical communications information beyond line of sight between land-based MAGTF, sea-based, and Joint C4I elements. The Marine Corp Stationary Lighter than Air Platform (MCSLAP) will provide expeditionary communications relay capability at remote sites within the MAGTF area of interest to decrease reliance on non-terrestrial based specialized communications systems. As an organic asset, time and bandwidth issues should not be an issue. MCSLAP was cut during the POM cycle.

MCSLAP (Figure 4-12) consists of an aerostat, helium, fiber optic tether, 150 lb interchangeable/removable payload, mooring system, motorized winch, and supporting equipment. The system can be easily transported via HMMWV and has minimal set up and tear down time. Once the system is set up, it has the capability to remain on station for up to 30

days. With a lifting capability of 150 lbs., MCSLAP has the ability to carry not only data communication equipment, but sensors and radar related devices as well. At the proposed altitude, MCSLAP will have the potential to relay data communications well beyond line-of-sight.

Figure 4-12 Marine Corps Stationary Lighter than Air Platform

MCSLAP should have the maneuverability and versatility to be able to support the rapid communication needs of EMW. However, problems may arise during inclement weather. High winds or heavy rain may impede the ascent and/or descent of the aerostat.

4.2.2.1.2 Joint Land Attack Cruise Missile Defense Elevated Netted Sensor

The Joint Land-Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS) consists of an aerostat with radars to provide over-the-horizon surveillance for defense against cruise missiles. JLENS is primarily intended to tackle the growing threat of cruise missiles to US forces deployed abroad. The system enhances cruise missile detection and engagement ranges with current air defense weapons such as PATRIOT, Navy SM-2 missile, the Advanced Medium Range Air-to-Air Missile (AMRAAM), and ultimately the Medium Extended Air Defense System and the Corps Complementary Low Altitude Weapons System (CLAWS).

JLENS will operate at altitudes between 10,000 and 15,000 feet; be capable of detecting long range, terrain masked targets; and provide an effective fire control solution for joint theater air and missile defense weapon systems. Additionally, it can operate from sites on both land and sea, and is tactically relocatable. Comparing these capabilities against the performance of our current sensor systems, the value added of JLENS is readily apparent.

This system could easily carry a relay payload. The Army submitted requirements for a communications relay payload to the JLENS program office.

4.2.2.1.3 High Altitude Long Operation Network

High Altitude Long Operation (HALO) Network, a commercial system, is a proposed broadband wireless metropolitan area network. Angel Technologies Corporation is designing this system to provide a broadband communication network covering an area approximately 50 to 75 miles in diameter. The Proteus aircraft will act as the central hub to the network; however, it will still work in conjunction with satellites already in orbit. The major advantage of using an aircraft as the hub is that centralizing it on a particular area will be relatively simple. If a particular area needs an airborne high-bandwidth link or if an area becomes too overloaded with signal traffic, one or more Proteus aircraft can be sent to that exact location. Another benefit to using an aircraft instead of a satellite is that the aircraft is easier to upgrade and repair, if needed.

Figure 4-13 illustrates how the HALO systems would be implemented in a commercial application. CONOPS for a military operation would be similar to those in a commercial application. The major difference between the two would be in the relay payload. Rather than supplying internet and cellular services, the military system would be supplying relay of the tactical internet and other military communications as appropriate/required. The aircraft, employed for the relay mission, could be either manned (like the Proteus) or an unmanned UAV. Since these are manned systems or smaller UAVs, altitude is limited to approximately 30-40,000 feet.

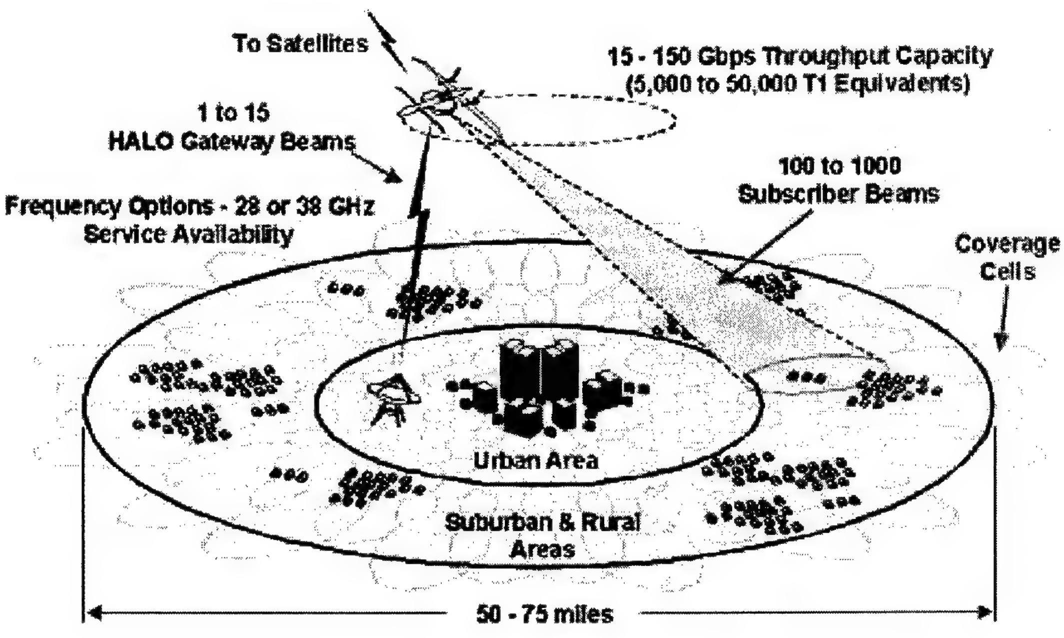

Figure 4-13 Typical HALO CONOPS

4.2.2.1.4 Sky Tower

Sky Tower was formed from its parent company AeroVironment for the sole purpose of commercial high-potential telecommunication applications. The platform used to implement Sky Tower is known as the Helios aircraft. This aircraft is a joint effort between AeroVironment and NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program. Helios is

a solar-powered UAV with the ability to operate at altitudes between 60,000 and 70,000 feet for up to 6 months at a time. Flying above weather and commercial aircraft, Helios can almost be considered a low-flying geostationary satellite. Sky Tower may function similar to a satellite, but it does not carry many of the disadvantages of a satellite.

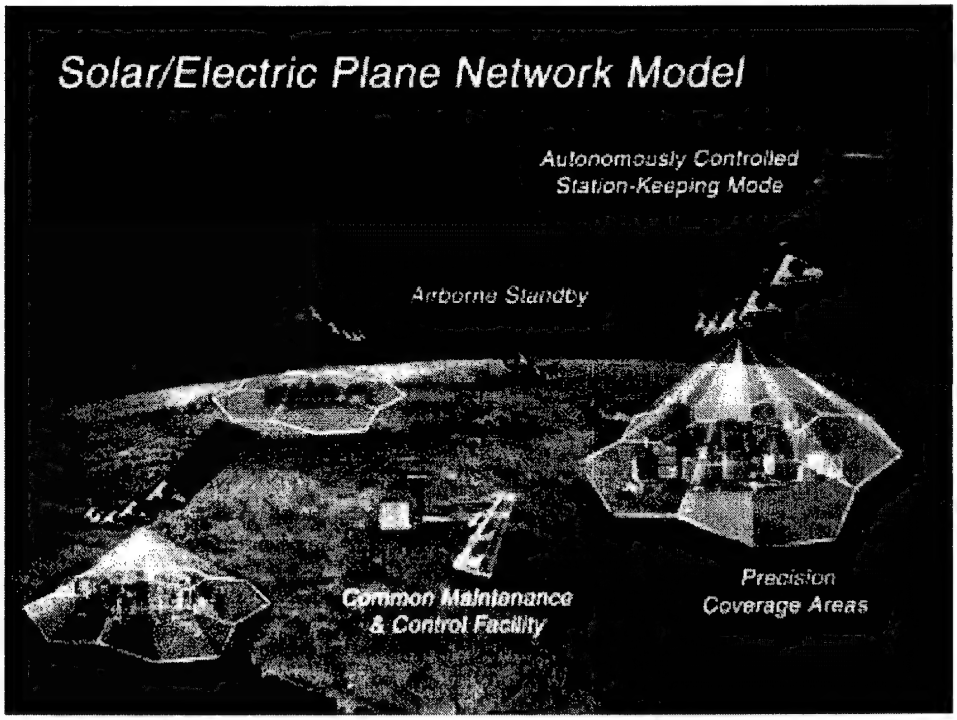

Figure 4-14 SkyTower CONOPS

Because Sky Tower flies tens of thousands of feet lower than a geostationary satellite, a signal's time delay nearly vanishes. This also means less power is required to reach Sky Tower. Another advantage of using Sky Tower is cost. It will cost significantly less to launch and maintain Sky Tower than it would a satellite. In addition, because Sky Tower can take off and land, it is exceptionally maneuverable and easily upgradeable. Sky Tower can be placed directly above the area needed, and moved if need be.

4.2.2.2 Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) serve many purposes. These systems range in size from small handheld systems to large, business jet/737s. While most have been designed for reconnaissance purposes, many have the ability and space to carry additional payloads. In this case, the payload would be a communication relay.

4.2.2.2.1 High-Altitude, Long-Endurance UAV

High-Altitude, Long-Endurance (HALE) UAVs are typically the size of business jets or 737s and carry powerful, sophisticated synthetic aperture radars and other sensors. Cruising at altitudes between 45,000 and 65,000 feet, they survey large geographic areas and provide near real-time, high-resolution reconnaissance imagery. With their ability to provide the big picture, HALE

UAVs fulfill much the same function as the manned U-2 spy plane. HALE vehicles can stay airborne for 24+ hours at a time. Pilots on the ground control them remotely. With the help of satellite links, it is possible for an operator located in Nevada to fly a Predator or Global Hawk over Iraq.

4.2.2.2.2 Small Unmanned Aerial Vehicle

This class of UAVs contains vehicles that are up to 6 feet long and weigh up to 90 pounds. Their military mission: short-range, "over the hill" reconnaissance forays to detect nearby threats on the battlefield. This category contains vehicles like Dragon Eye, a current USMC program still in its development phase. Many small UAVs are planned to be man packable.

Current research has shown that the next conflict will most likely be fought in complex terrain/urban environments where LOS will decide the survivability of the small unit/scout. The small unit/scout is limited in its reconnaissance and surveillance mission only by what it can or cannot see. Small UAVs with Vertical Take-off & Landing (VTOL)/Non Line of Sight (NLOS) capability would increase the "sight" of the small unit/scout by going around a corner or between buildings where LOS is broken and giving a visual image to the operator in near real time.

4.2.2.3 Roll-On Beyond Line-of-Sight Enhancement

Roll-On Beyond Line-of-Sight Enhancement (ROBE) is the first system in a family of Scalable, Modular, Airborne, Relay Terminals (SMART). The system is comprised of a roll-on/roll-off pallet that can be placed inside an aircraft to extend communication distances. Currently, ROBE is being tested in air refueling tankers like the KC-135. Future SMART systems will be scaled down to fit inside UAVs and ground- or sea-based vehicles. In concept, planes equipped with ROBE technology become flying network nodes that can relay and translate vital data link information and collect and relay information. The Air Force has contracted delivery of this system and is undergoing interoperability testing.

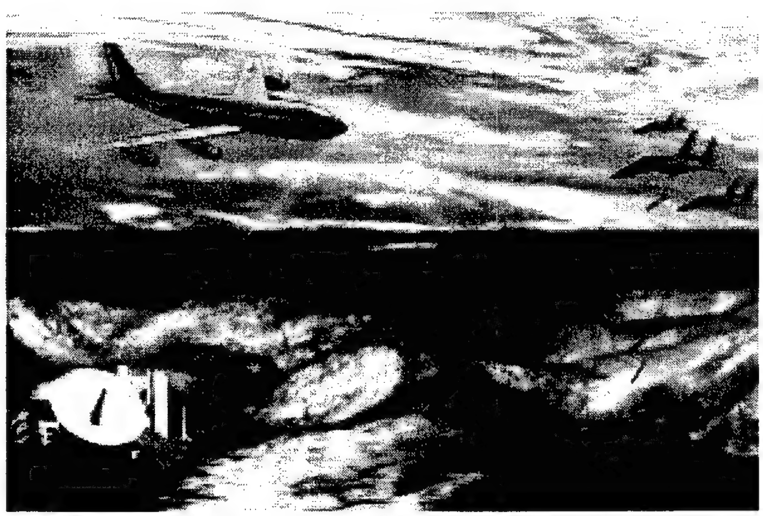

Figure 4-15 ROBE CONOPS

The major problem with using tankers as BLOS relays has to deal with their location. Tankers are always airborne when other aircraft are flying. However, they are typically not in the immediate battlespace. Hence, forward troops may not be able to reliably use the ROBE systems. Placing ROBE inside other aircraft, such as the MV-22, MH-53, or C-130, may prove to be more beneficial. These aircraft fly over the battlefield on a regular basis, and more importantly, they tend to fly the same path in which BLOS communication would be needed.

4.2.2.4 Airborne Communications Node

The Airborne Communications Node (ACN) is a multi-purpose BLOS communications relay. The ACN is network based. Given that it is a module, it is independent of platform. ACN is planned to be scaleable. At a tactical level, the system is designed for small UAVs. A 120-pound payload is planned for theater platforms (MV-22, CH-53, UH-1, etc.) while a 742-pound platform is available for large "strategic" assets.

The ACN is a wideband multi-mission communications relay node. When completed, it will extend the functionality of JTRS. THE ACN is JTRS compliant. Therefore, it can handle the mobile, ad-hoc, auto-configuring network requirement. Major advantage for the ACN is that is provides a bridge between legacy systems and future communication systems.

4.2.2.5 Adaptive Joint C4ISR Node

Adaptive Joint C4ISR Node (AJCN) is a programmable, multi-function payload with the ability to be installed in a UAV, manned aircraft, or other platforms. It is designed to provide autonomous BLOS communications as well as several other intelligence-related tasks. The importance in this system is that it can perform many functions simultaneously. Most of the testing has been done onboard a UAV platform, though testing with other platforms is expected. Equipped in a UAV such as Global Hawk, AJCN could perform concurrent communication, signals intelligence, electronic warfare, and information warfare missions. This becomes especially useful when airspace is limited and critical. Another important element to this system is that it can also bridge dissimilar communication systems, such as military-to-civilian and country-to-country.

AJCN enhances and augments the current and future military communications infrastructure. By improving theater-wide communications, as well as out-of-theater reachback, AJCN improves interoperability and information sharing. An important benefit is the ability to provide communications without the need for infrastructure to be in place first for early entry forces. It is as self-deployable as the platform that carries it. When deployed, it provides warfighters with instant communications support for existing military radios on the ground. AJCN services include range extension, cross-banding support for dissimilar radio interoperability, tactical packet channel switching, surrogate satellite, and a high-speed throughput airborne infrastructure with access both in and out of theater.

The AJCN payload is being designed to provide "any-to-any" connectivity among users and services for both data and voice. This any-to-any connectivity also extends to other AJCN platforms through air-to-air crosslinks and self-organizing high-speed, high-throughput airborne communications backbone. The payload will provide any required message encryption translation and data buffering. The AJCN could very well derive benefits from the on-board SIGINT capability. The SIGINT payload could help identify frequencies that are causing network interference and help to adjust on-board antennas to help defeat these interference problems before the user even realizes anything has happened.

The AJCN will be capable of establishing a basic airborne communications network for forced entry operations, and will allow for network growth and expansion as the theater matures. Additionally, the AJCN will allow for immediate operations, precluding the use of ground retransmission emplacement. Furthermore, the AJCN can be dynamically controlled and configured while in flight. This real-time re-programmability makes AJCN adaptable to support rapidly evolving mission profiles.

Cost could be a large advantage for AJCN. The only real costs are the payload itself and integration/modification costs for the airframe. AJCN can be placed on existing platforms, and it is interoperable with current and emerging communication systems. This means it could be functional in both wideband and narrowband communications across the full 30 MHz - 2 GHz spectrum.

4.2.2.6 Surveillance Warfighting Array of Reconfigurable Modules

Surveillance Warfighting Array of Reconfigurable Modules (SWARM) is a system of low cost, expendable UAVs operating as a cooperative group. Each module is a 4-foot-long, 20-pound plane with a 4-foot wingspan and a 4-pound payload-enough capacity for any type of camera, microphones for eavesdropping, mini chemical and biological detectors, or even, potentially, a small weapon. Base configuration weighs 4.5 lbs, which includes the airframe, avionics, and communications packages. Depending upon configuration, SWARM planes are estimated to cost $2,000 apiece with relay capability. In most cases, this makes the system a disposable asset. Figure 4-16 illustrates several possible UAV body designs.

SWARM aircraft are designed to be launched from a catapult or helicopter and to operate at 60 knots, meaning it can be deployed in most weather. The launched SWARM will link up with each other and fly in formation. The SWARM fleets will be given nothing but a destination and a mission. They will be expected to identify the best route, the most effective formation, the objects and activities to observe and image, and the information to send back to base. In the event the formation is broken, each UAV will have the ability to replace individual losses by re-configuring with the other units to complete the mission with minimal delay.

The ultimate vision for SWARM is to provide an autonomous network of UAVs that can relay communications, provide internet in the sky, provide GPS data to ground based forces, as well as provide a means to carry small payloads anywhere with minimal infrastructure requirements.

4.2.3 Elements of the Spaceborne Layer

The spacebome layer consists of deployed commercial and military communications systems ranging from low space orbits to geostationary orbits.

The overall objective of the spacebome layer is to provide assured communications to any place on the planet. This is accomplished through a network of satellites. These satellites have the ability to bounce traffic between all three zones.

The priority of this range extension capability is to help support SA and C2. A secondary priority is to provide a Combatant Commander (COCOM) the same picture at his forward deployed command post as he would see at the Pentagon.

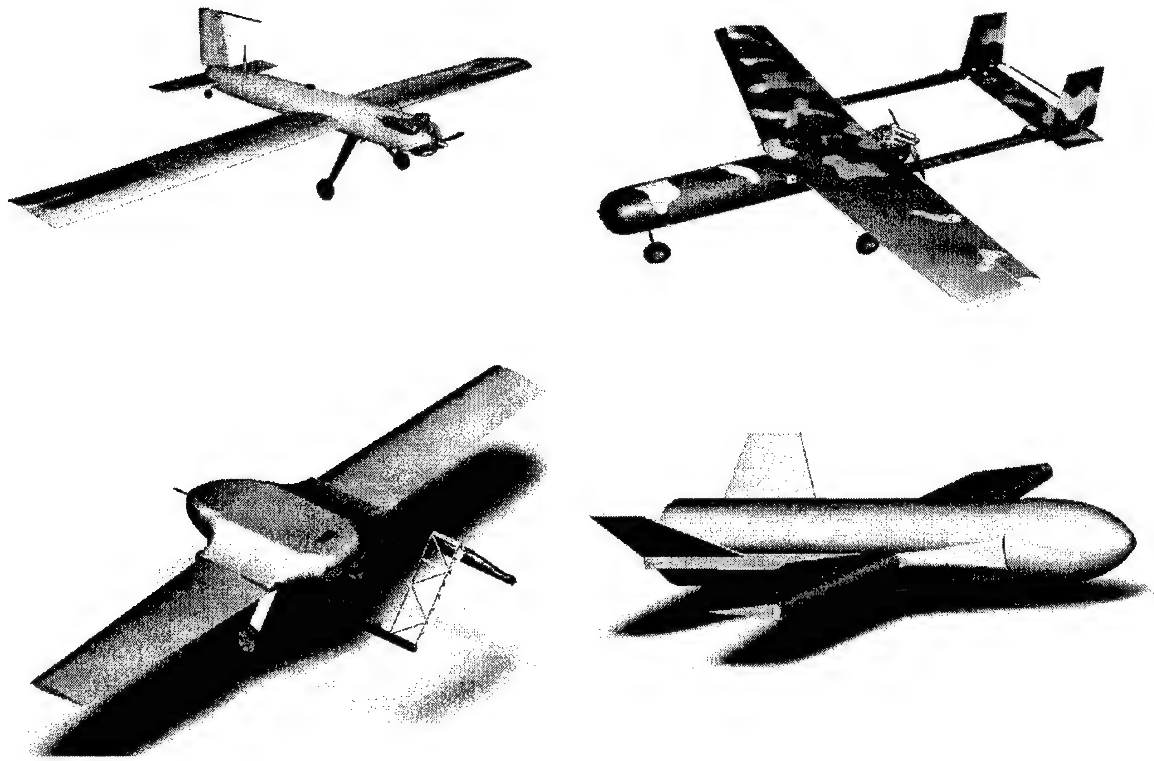

Figure 4-16 SWARM Configurations

Satellites have long been used to communicate over extreme distances. Using satellite relays almost guarantees communication anywhere in the world. Satellites have also proven themselves a faster and more reliable means of communications than attempting to bounce signals directly between a separated transmitter and receiver. The downfall to satellite communication (SATCOM) is cost and availability. This ultimately restricts most satellites from being organic solely to the United States Marine Corps.

The cost of manufacturing and launching a satellite into orbit limits not only the number of satellites launched, but also limits ownership. This usually results in several organizations piggy-backing on one satellite. Satellite time has become limited and rather congested. In an attempt to resolve this problem, the size of satellites and their altitude began to decrease.

The size of satellites has been dropping steadily over the years. As technology advances, smaller satellites are becoming increasingly popular. It is now possible to launch a 20 kg satellite into orbit for less than $200,000. Satellites the size of soda cans are also being tested; however, many of these satellites are used in controlled fall experiments rather than being put into orbital patterns.

Orbiting satellites are divided into three distinct classes: Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO). The distinction is based upon the orbit distance from the Earth. Figure 4-17 below illustrates the three classes.

Low Earth Orbit (LEO)	Medium Earth Orbit (MEO)	Geostationary Orbit (GEO)
750 – 1,800 km	10,000 – 14,000 km	35,700 km
Scan Angle: ±57.2/47.1°	Scan Angle: ±21.5/17.1°	Scan Angle: ±8.25°

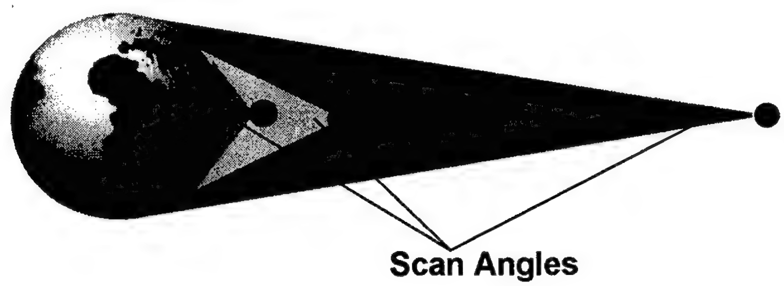

Figure 4-17 Relative Earth Coverage by LEO, MEO and GEO Satellites

4.2.3.1 Low Earth Orbit

LEO satellites are located approximately 400 to 1,000 miles above the earth's surface. At this altitude, it is not possible for the satellite to have a predetermined location above the earth. Therefore, LEO satellites must orbit the earth at high speeds. If only one satellite were used, communication windows would be brief and intermittent. In order to be able to accurately communicate using LEO satellites, a system of satellites is required. By using numerous satellites, information can be passed from satellite to satellite in order to keep a consistent link between transmitter and receiver.

The low altitude of these satellites also results in a shorter time delay and less required power than satellites at higher altitudes. A typical LEO system has 20 - 40 msec latency. That means it takes 20 - 40 msec for a signal to travel from the transmitter, through the satellite, and down to the receiver. This latency is directly related to the distance the signal travels. Leo satellites tend to be smaller and less expensive than higher altitude satellites. However, costs may rise considerably because numerous satellites (often in the 100s) are required in order for a LEO system to function correctly. Launching one satellite could be relatively cheap, but launching in the order of 100 satellites and making sure all their orbits are synchronized may prove to somewhat complicated and costly.

4.2.3.1.1 Small Satellites

Current research shows a vast interest in small satellites. Small satellites can be categorized into the following groups: femto- (<100g), pico- (0.1-1kg), nano- (1-10kg), micro- (10-100 kg), and mini-satellites (100 -500 kg). This significant decrease in size also comes with a

reasonable decrease in cost. This savings is not only in production costs but also in the launch and service costs as well. These decreases could lead to expendable, small unit launched tactical BLOS relays. For example, consider the two figures below. The figure on the right is the "satellite". In this case, it is constructed inside a tin can. The launch vehicle (shown at left) is relatively small.

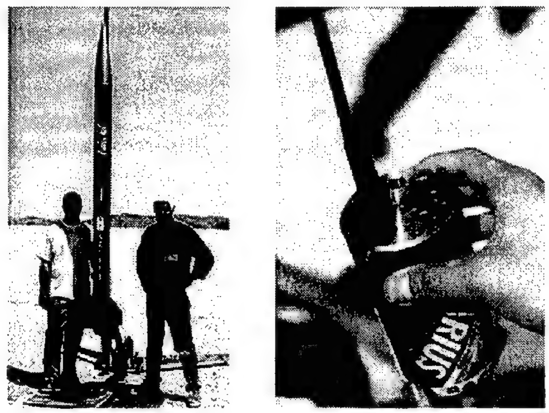

Figure 4-18 Nano-Satellite Technology

Another possible method to launch these "small" systems is via modified aircraft payloads. Orbital Science Corporation in conjunction with Hercules Aerospace Company created a "missile" for launching small systems. Simply, the launch vehicle is dropped from an aircraft. They can launch up to 450 kg into a LEO slot and up to 100 kg into a geostationary transfer orbit.

The small size may allow a satellite to be launched via artillery or mortar round and used as a controlled fall satellite link. Note that, since the satellite is falling through the atmosphere, the communication window would be limited. The size of the satellite and the rate of fall would determine duration and distances transmissions could be sent. In the case where short duration communications are required, this method could prove useful. Figure 4-19 illustrates a typical low altitude launch. The time aloft is a function of wind strength. Once the system starts to descend, communication distance will be reduced over a 15-minute period.

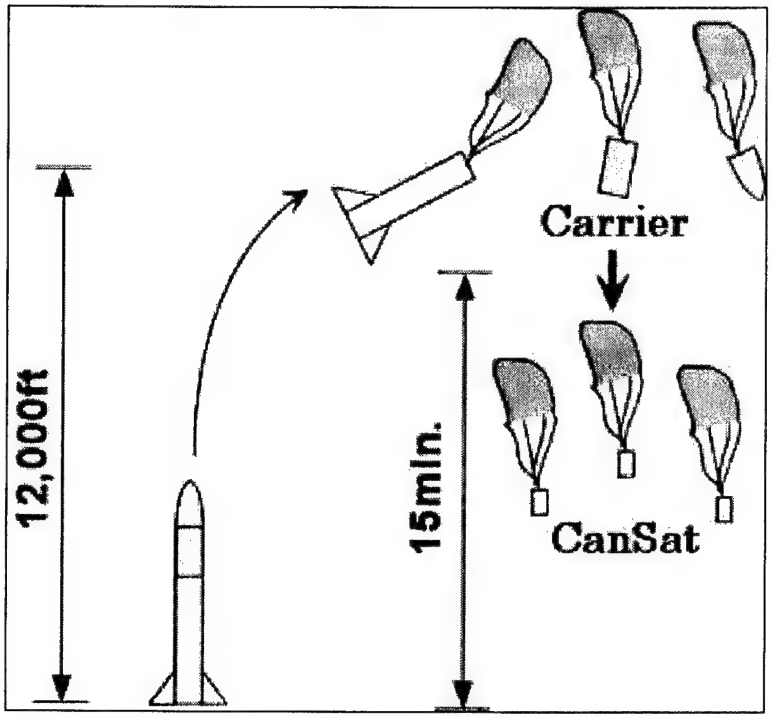

Figure 4-19 Low Altitude Deployment

4.2.3.1.2 Expeditionary Tactical Communications System

Expeditionary Tactical Communications System (ETCS) is based upon the commercial IRIDIUM system, modified to provide a push-to-talk netted (one to many) voice and data capability. IRIDIUM is a system of 66 LEO satellites that was originally used for commercial global satellite communications. ETCS will provide BLOS and OTM communications between the seabased C2 nodes and elements ashore down to the dismounted company commander and reconnaissance team. This effort will include the integration of ETCS into Marine Corps C2 systems to include OTM COC platforms to enable the passage of data in support of a common tactical database being developed by the Digital Combat Operations Center (DCOC) team[6]. In conjunction with the Reconnaissance, Surveillance, and Target Acquisition (RSTA) team, ETCS will also be integrated to link an unmanned ground sensor (UGS) to the seabase.

Figure 4-20 illustrates how the ETCS will be employed. Each person requiring communications capabilities would be given a small handheld "telephone". This telephone is used to pass your information up to an Iridium satellite. The Iridium infrastructure is then responsible for routing your data to the appropriate recipients.

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[6] DCOC is being developed by the USMC Warfighting Lab in conjunction with USMC System Command's UOC, EFV, ONR's Littoral Warfare Future Naval Capability program and General Dynamics. The goal is to put COC capabilities into on-the-move platforms such as the EFV and the HMMWV to the infantry battalion commander for the surface and vertical employment during STOM.

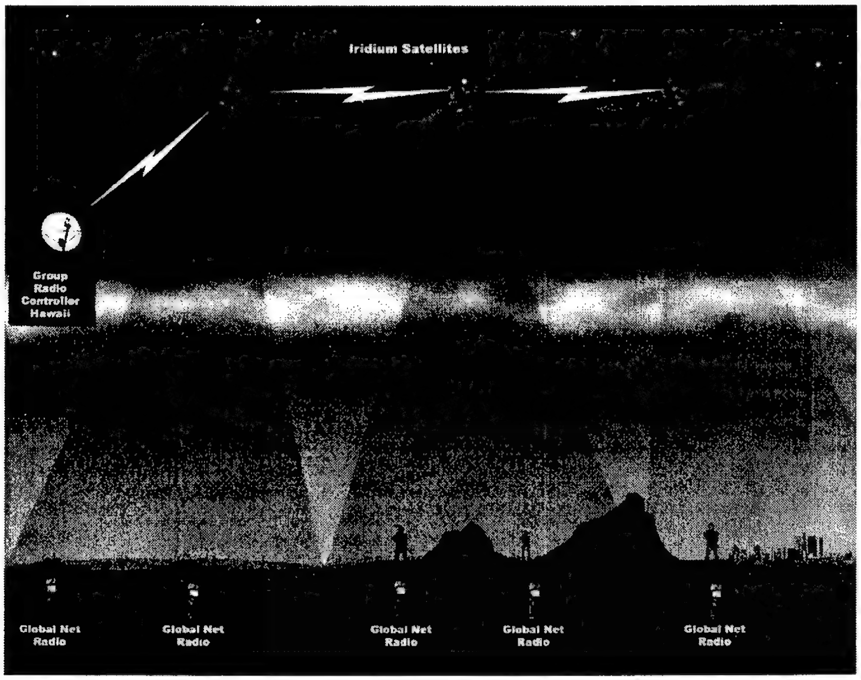

Figure 4-20 ETCS CONOPS

Commanding General, Marine Corps Combat Development Command, issued a directive to experiment with ETCS during Exercise Sea Viking-04. Because of this directive, ETCS will be installed on each ship in the Amphibious Ready Group during Sea Viking 2004. At the conclusion of experimentation, the Marine Corps Warfighting Lab will provide lessons learned and refined requirements statements to MCCDC for a long-term solution for MAGTF BLOS communications.

This system was used extensively and quite successfully during Operation Iraqi Freedom. Lessons learned regarding their use will echo the limitations documented in Section 4.2.3.1.2. Primarily, coverage area was limited (no access within a building) and costs were high. Other issues include the size of the radio itself. The Iridium phone is significantly larger than the traditional cell phone. However, ETCS implementation promises a smaller, more user-friendly access device.

A second legitimate concern with ETCS is in the satellite constellation itself. The constellation was established as a commercial venture. Because of insufficient interests, the constellation was shut down. The DoD stepped in and purchased the rights to use the system. The question that needs to be answered is how long will the DoD continue to support/run the Iridium constellation?

4.2.3.2 Medium Earth Orbit

MEO satellites operate between 1,000 and 23,000 miles above the earth's surface. This altitude is still not high enough to allow for a stationary position; therefore, MEO satellites travel in an orbital pattern similar to LEO satellites. The extra height allows the satellite to cover a larger area for a longer time. This results in fewer satellites per system. However, the altitude

also increases the latency time to approximately 50 - 150 msec. This creates a longer time delay during transmission, as well as more required power.

MEO satellites do not differ from LEO satellites significantly. The advantages and disadvantages between the two cancel each other. Fewer MEO satellites are required than LEOs, but the cost tends to rise in sending a satellite higher into space.

4.2.3.3 Geostationary Earth Orbit

GEO satellites are located 22,300 miles above the earth's surface. At this altitude, the satellite is locked into the earth's orbit. This enables the satellite to rotate at the same speed as the earth, giving it a fixed position. One GEO satellite has the ability to cover approximately 40% of the earth's surface. Three satellites can provide constant coverage over the entire earth. This drastically cuts down on the number of satellites per system, but can cause several concerns.

With latency as long as 0.24 sec, transmission through the satellite can become congested and limited. Because the satellites are at a fixed position, space over heavy populated areas is also restricted. This can create competition over availability and usage time. GEO satellites also tend to be located low on the horizon, which can make locating a satellite arduous and timely. Cost is most likely the largest disadvantage for a GEO satellite. The cost of building, launching, and maintaining a GEO satellite makes it near impossible for single service ownership.

4.2.3.4 Joint Range Extension

Joint Range Extension (JRE) is another system being developed as a possible solution to BLOS communication problems. The concept of JRE is to acquire the ability to pass secure voice and data signals by modifying current communication programs, specifically TADIL J. JRE will extend the range of TADIL J without having to use a dedicated airborne relay. JRE does not produce its own signals, but rather acts as a link between a Joint Tactical Information Distribution System (JTIDS) terminal and a SATCOM system. Figure 4-21 illustrates how JRE could be used to link different elements at varying distances. With its ability to be used in all the zonal areas, JRE could be an exceptionally versatile asset. In the figure, SATCOM is used as the range extension mechanism. SATCOM does not have to be part of the JRE network. JRE has been designed such that BLOS communications can be provided without airborne assets. In place of SATCOM, one might have SIPRNET, STU, Mobile Subscriber Equipment (MSE) or some other "network".

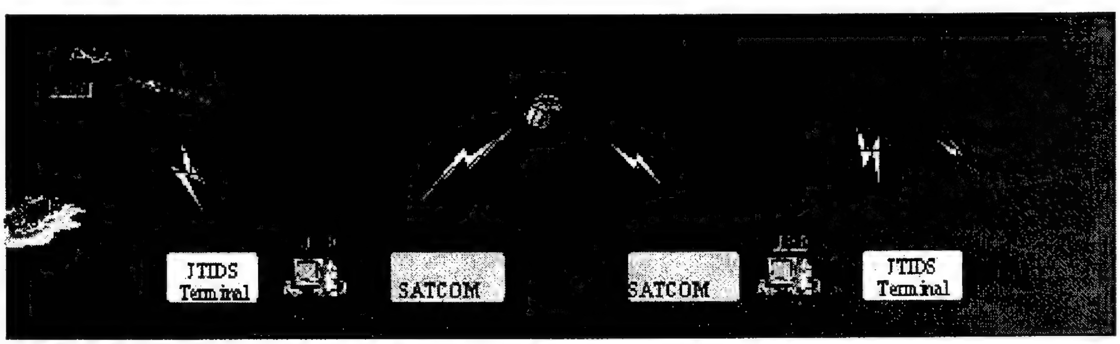

Figure 4-21 Simple JRE Configuration with SATCOM

JRE is intended to interface up to four JRE media with one Multifunction Information Distribution System (MIDS)/JTIDS terminal / network simultaneously and encompass data forwarding filters based on geography, track identity and or J-Series message numbers. Receipt / Compliance protocols will need to reflect the chosen media time latencies and the monitoring and net management facilities will also be specific to the chosen medium.

4.3 Concept of Employment

4.3.1 General

As mentioned earlier, assets in all three layers and zones will provide for a robust, redundant, and capable C4 network that contains the tools to achieve a seamless, reliable, configurable, mobile and, most importantly, survivable networked over the horizon architecture.

A conceptual view of how these assets might be deployed will work to help provide tactical and theater level users the Command, Control, Communications, and Computer (C4) connectivity they require is provided below.

4.3.2 Pre-strike

Tactical UHF and SATCOM capabilities will serve as the C4 BLOS foundation for early, pre-strike operations for both the tactical and theater level assets. Single channel SATCOM is typically easy to install, easy to operate, and reliable. This will be the first means of BLOS communications.

Prior to strike operations, tactical SATCOM will be augmented by high altitude UAVS. The high altitude, long-loitering UAVs will blanket the area with theater level communications coverage. The payload will be either an ACN or AJCN package. These systems can provide covert operatives and C2 personnel situational awareness.

4.3.3 Strike Operations

Prior to commencement of action, high altitude, non-tethered aerostats should be deployed. Once airborne, these systems can help reduce the demand for satellite relays and provide communication gateways for the strike force. Strategic UAVs carrying the relay payloads should also be deployed at this time. These systems, acting in concert with the aerostats, will be the primary BLOS relay assets for the duration of the assault landing phase.

If assault and/or support aircraft have enabled the relay capability of their JTRS radios, they will be acting as relay hosts between the assault waves and the afloat COC. Communications between assault waves will be via LOS relays. Each wave will be communicating via WLAN. Each of these WLANs are connected via BLOS systems. In the push/pull architecture, subscribers of SA data could be receiving their information from either airborne or afloat relay assets.

4.3.4 Operations Ashore

Once ashore, the full complement of BLOS assets becomes available to the combatants. Ashore personnel can start launching tactical UAVs and deploying tethered aerostats. Naturally, all transport vehicles equipped with relay capable radios will also act as BLOS systems. Once Marines are ashore, four distinct BLOS scenarios might be encountered. The

first two are desert and topographically featured earth (mountains, caves, tunnels, etc.) environments. The last two are not traditional BLOS issues. BLOS communications issues traditionally deal with terrain masking RF signals. However, other natural features can mask signals such as natural foliage and man made features such as buildings.

4.3.4.1 Desert

Deserts are the "ideal" terrain for any BLOS architecture. For all practical purposes, the area is statistically flat. Minimal assets are required to relay information back and forth. Airborne assets are required to fill in any "holes". These assets might include aerostats, UAVs, manned aircraft with relay payloads, etc.

4.3.4.2 Topographically Featured Earth

Regions of the world that have terrain elevation changes of more than a couple of meters fit within this category. As the elevation changes become more pronounced, the BLOS communications problem also becomes more evident. In truly mountainous regions like Afghanistan, numerous airborne assets will be required to provide complete communications coverage. Naturally, less mountainous regions will require fewer assets.

The lowest airborne asset should be located such that it will provide complete coverage in the valleys. Since these systems will be fairly close to the ground, they should be low observable, tactical UAVs. Larger UAVs are then located above these to connect the valleys together. Additional layers are added until the Marine in the valley has access to the GIG. Modeling will be required to determine exactly how many assets and at what altitude the asset should fly for a given geographical region.

4.3.4.3 Foliage Issues

Foliage can be anything from a traditional forest to jungle/rain forest regions of the world. In this case, rather than terrain masking the signals, the signals are adsorbed by the foliage. Higher frequencies are adsorbed more readily than lower ones. When communications out of these environments become a problem, two options exist. First, frequencies can be lowered. This is not practical unless everybody decides to operate at the lower frequencies. The prudent choice would be to establish a relay network at the height of the canopy. Enough signal strength exists at the canopy height for a relay to reliably receive a signal and then retransmit it to others.

4.3.4.4 Urban Environments

Urban terrain is probably the most challenging environment for signal planners. In urban environments, two problems exist. First, the buildings block signal transmission. Second, if Marines are inside a building, communications between them and the rest of the "world" may be limited. The easiest manner to get a signal out of a building is for the Marines to place small relay boxes around the interior of the building as the work their way through the infrastructure. Once a signal is outside of the building, small, tactical UAVS or even micro-UAVs will be required to provide BLOS relay. These systems will be small enough to maneuver within the confines of streets to provide the required communications assets. This portion of the problem is identical to a very mountainous region with deep valleys.

4.4 The Way Ahead

4.4.1 Decision Criteria

The recommendations from this survey are based on the three zones described earlier in this chapter and a working knowledge of communications theory and practice. Some of the criteria used to make the decisions were: maneuverability, coverage area, use of organic equipment, sustainability, and cost. Not all of the criteria were pertinent to each zone; however, using each one helped significantly in the decision process.

Just as the MACCS is a family of systems, so too must any BLOS communications solution. While one system, e.g., satellites, may solve the majority of the BLOS problems, a single system is not the optimal solution. Placing assets in the multiple layers/zones described previously has several advantages.

- **Flexibility**: rapid reconfiguring/thickening of the network with airborne platforms supplements coverage of dynamic, high-tempo, non-linear, non-contiguous operations executed over large distances.
- **Reliability**: ample capacity and routing alternatives in the event of component failure, additional mission demands, etc. Most range extension capability will exist in the vertical portion of the network, so airborne and space layers together eliminate a potential single point of failure.
- **Durability**: adequate capacity and routing alternatives exist when an adversary attempts to degrade the network. The system provides for graceful degradation and restoration with little noticeable effect on information flow to the warfighter. Complicates an adversary's targeting problem-must target multiple components of the network to have any impact.
- **Capacity management**: the ability to manage traffic loading between space and airborne layers; to offload traffic from the satellite network to the airborne layer when necessary, making satellite capacity available for other requirements.
- **Graceful Degradation**: The combination of redundant network components, multiple paths and automated network operations allows the information network to provide continuous support to critical warfighting operations in spite of enemy efforts to degrade the network. Although some low-priority users may notice a reduction in network performance, the movement of mission-critical information will continue relatively unchanged as network operations systems automatically reallocate network resources. The combination of layers enables the continual adjustment of traffic load between space and airborne layers.

4.4.2 Observations

Prior to detailing possible BLOS/BLOS options, several generic observations were made. These observations may provide additional insight into why certain options were recommended.

- A desire exists within the Marine Corps to ensure that any BLOS option chosen is not solely based upon satellites. Satellites are expensive, bandwidth limited, and time

shared. The possibility exists that the asset may be unavailable due to a higher priority message set being transmitted.

- Unmanned and/or standoff systems are preferred. If such a system were discovered, additional and possibly significant assets must be expended to determine who is using the asset as well as where control point is located. This increases the Marines ability to remain covert when needed.

- Utilize modified ad hoc mesh network topology. Any networked BLOS option chosen should be self-reconfigurable. That is, nodes should be able to "appear" and "disappear" as needed. Network must be able to adapt to this on-the-fly condition.

- The answer to solving the BLOS is not to establish terrestrial based relay sights. These sights require significant manpower to assemble and defend. Ultimately they become easy and high priority targets.

- The proposed architecture provides for a robust, redundant network. However, the system needs to be modeled to determine numbers and placement of the BLOS assets for various missions. In other words, the remaining question is: How many of each type of asset are required?

- The Marine Corps desires to have organic BLOS assets. This is an excellent idea up to a point. Terrestrial and some airborne systems are quite doable as an organic asset. However, other systems such as some of the larger aerostats and UAVs are not practical even though possibly feasible. Reason for this is that the Marine Corps will not fully utilize such an asset. In addition, in a Joint environment, these assets will be some of the first platforms retasked by the Joint commander for their use.

- Conceptual solutions have been presented in this section. To fully develop a solution, a communications model must be used to determine exact numbers and locations of the assets. In some cases, the model will be able to illustrate problem areas that would not be evident to the signal planners.

- Surface combatants lack an adequate communications capability to operate in support of maneuver forces operating ashore. Airborne relay capabilities for both UHF and VHF LOS radios have been demonstrated in exercises such as Extending the Littoral Battlefield (ELB). The follow-on ONR effort is known as JTF WARNET and will include a prototype to be deployed on a 7th Fleet expeditionary strike and carrier strike groups during 2004. Unless JTRS picks up this effort, there is no funded program to transition either JTF WARNET or the ELB technology to provide the necessary airborne relay capability.

- The BLOS solution chosen by the Marine Corps must work within the Joint community. Stovepipe solutions are outdated. The graphic below (Figure 4-22) does an excellent job of illustrating this problem. Each force is using their "own" assets to access the GIG. To work within the FORCEnet/Network Centric Warfare arena, systems must be interoperable. This is illustrated in the Figure 4-23.

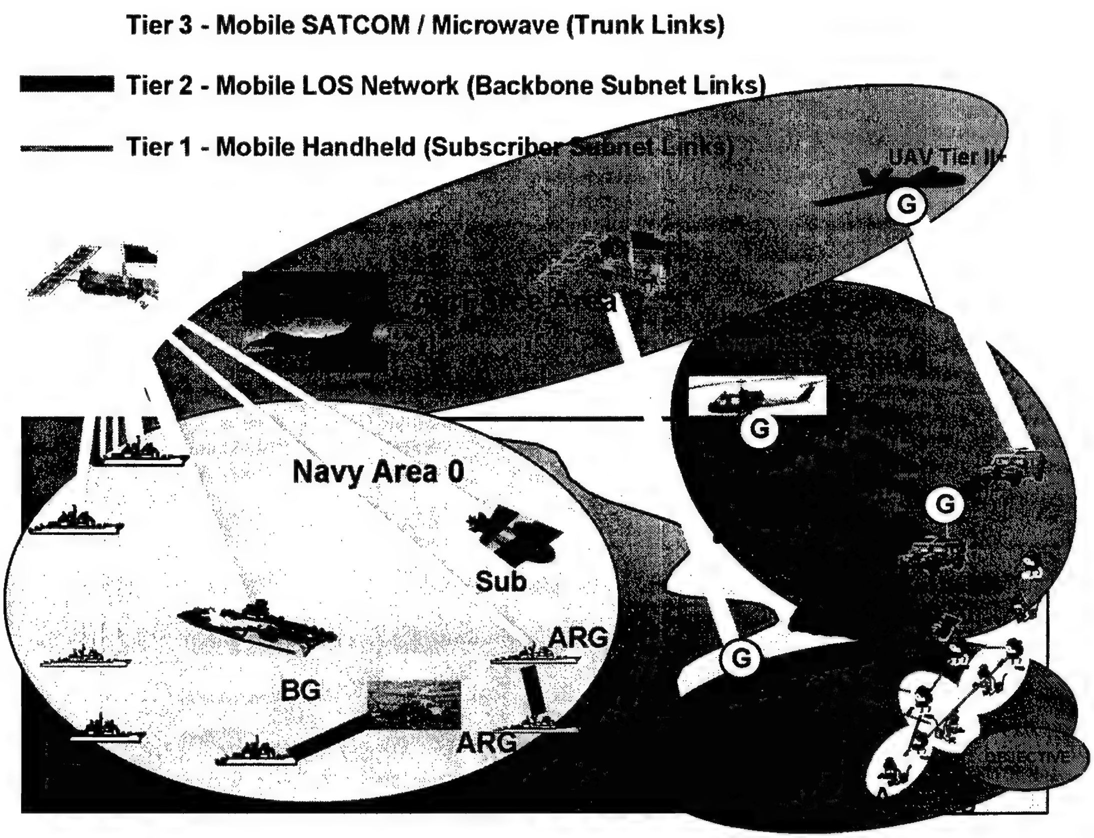

Figure 4-22 Current Interoperability Shortfalls

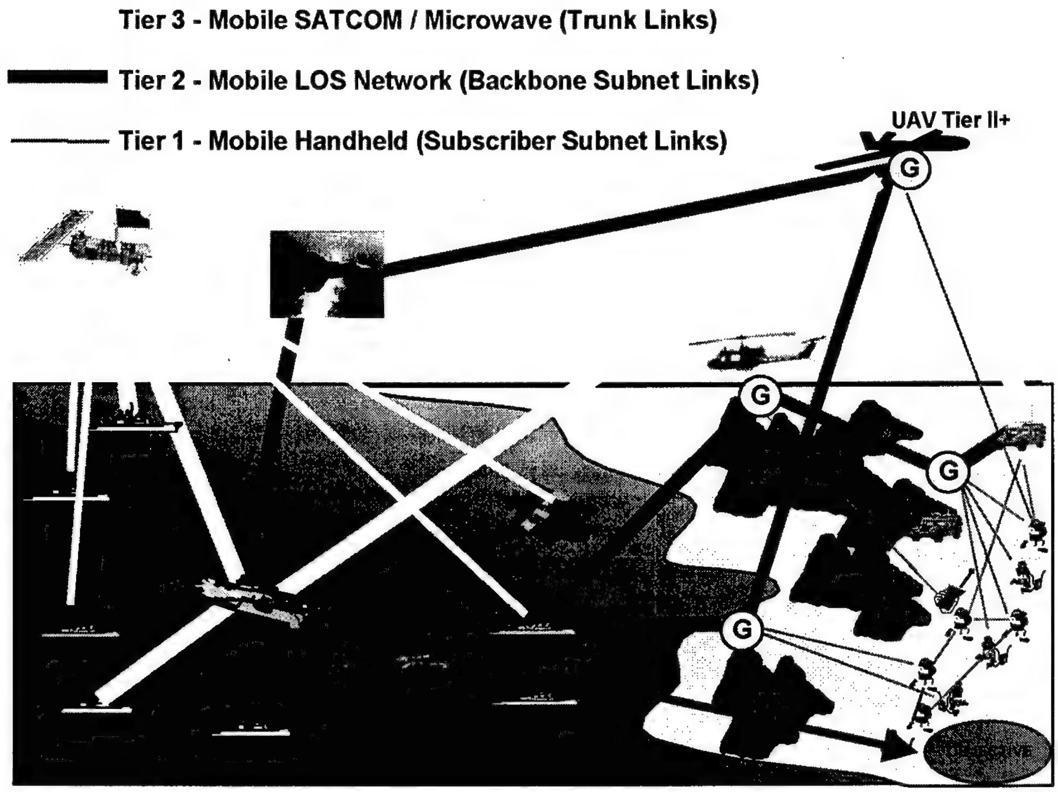

Figure 4-23 Communications Architecture for 2015 Joint Community

4.4.3 Intra-Zone Communications

Recall that Intra-Zone communications is communications occurring within a given unit (tactical communications). Typically, this ranges from 30 to 100 miles. Some assets in this region are quite mobile while others are stationary. Hence, no single solution will work for all assets. Several options exist that are worth further pursuit.

- JTRS BLOS capability. Native JTRS in conjunction with WNW can construct its own IP based network. With a few system modifications, this network could be expanded from those radios in the immediate vicinity to all systems that can be reached within the battlefield. As long as any given radio can talk to another, it can be used as a relay. Other forces have leveraged a requirement on the JTRS program office to provide this native BLOS capability within JTRS. It is recommend that the Marine Corps follow suit and place such a requirement on the JTRS program office. If such a requirement existed, BLOS communications could occur well beyond the 100 - 200 mile range.

- Digital Combat Operations Center is investigating an BLOS/On the Move capability. The program looks at placing "relays" on various vehicles in a group. As the group travels from one spot to another, this "special" vehicle can be used to provide BLOS communications for all that are within LOS of said vehicle. This program, if successful, could provide intra-zone BLOS communications for specific missions with the zone. This is an excellent option for a desert/relatively flat terrain.

4.4.4 Inter-Zone Communications

Theater level (Inter-Zone) communications are those occurring over many tactical regions. Majority of the assets required to provide BLOS communications for this zone are located in the airborne layer. These assets will be deployed in the late pre-strike phase and be used throughout the entire duration of the mission. Two categories of assets were discussed in the above COE: aerostats and payloads.

4.4.4.1 Aerostats

Aerostats can be either tethered or mobile. Mobile systems include the HAPS, HALO, and SkyTower systems. Tethered systems would include JLENS and MCSLAP. Both technologies have considerable potential. The Marine Corps should:

- Invest in mobile aerostat technology. Aerostats can be purchased by the Marine Corps to be organic assets. Both HAP and HALO technologies are feasible replacements for satellites.

  Aerostats potentially offer the best solution with direct line of sight and minimal path loss. For example, an antenna designed for SATCOM on-the-move at SHF can achieve data rates in the mega-bytes/sec while the same system to a traditional satellite will realize data rates in the kilo-bytes/sec.
- Invest in tethered aerostats. Tethered assets like MCSLAP are ideal systems for mountainous and urban environments. In both of these environments, higher look angles to the asset are required. This can only be achieved by having an asset overhead. High altitude systems may not be accessible.

4.4.4.2 Payloads

The various services and the joint community are already developing several payloads. Tactical UAVs will become the mainstay for the forward deployed warfighter. These UAVs are small enough to be carried in a vehicle or even "packed-in". Other payloads are designed for larger platforms. Both will be required. The following payload development should be followed/invested in by the Marine Corps:

- For large platforms, e.g., KC-130, V-22, H-1:
  - ROBE is being deployed by the Air Force in their tankers. Tankers are flying whenever aircraft are airborne. The Marine Corps, having their own aircraft, might be able to take advantage of the Air Force deployed ROBE systems. If the system is eventually reduced in size, it should be considered for deployment on both the H-1 and V-22 series air frames. Both of these platforms will be flying along the same routes as the Marines are traveling. It is also along these routes that the communications extension is needed.

- AJCN is another payload being developed for the joint community. This system shows promise. This is especially true if the size is reduced to work with all sizes of vehicles.

- ACN is a program that also shows promise. However, the Army is developing a payload similar to the ACN. Unlike the ACN, this program, Communications Relay Payload (CRP), is planned to have three "sizes". The Army plans to use the CRP as part of their Objective Force.

- The JRE program also deserves consideration. This program will provide the ways/means to extend JTIDS zones. As a secondary objective, it will also relay SATCOM and other data links. Note that this asset relies on satellites.

- Micro and Pico satellites have several unique features that make them attractive options. First, the cost of the satellite systems is quite low. Second, since the satellites are small, launch platforms can also be small. Universities are launching these systems in small, easily transportable rockets. As an emergency BLOS asset, these satellites are feasible. Marine Corps should invest in further research to determine feasibility. At a minimum, the technology should be followed.

4.4.5 Reach Back/Reach Forward Communications

Options in this zone are somewhat limited to SATCOM. The cost, complexity, and required height are key limiting factors here. In order to communicate halfway around the world, a given relay position must be at an extreme height. Using satellites seems to be the easiest option in this case. Using a series of lower altitude relays could be possible, but this would require numerous relays placed at predetermined locations. This not only becomes complicated but costly as well. The cost in reach back/reach forward communication will most likely be high in all cases, so using satellites already in orbit may be the most logical choice. Having an organic system strictly for the Marine Corps is not very likely for communications at these distances.

While the Marine Corps is unlikely to invest in their own satellite network, some SATCOM components are worth pursuing.

- Both amphibious and land vehicles would benefit from an on-the-move SATCOM capability. Ball Aerospace is providing antennae systems originally designed for the Air Force B-2 program to the Marine Corps for the EFV, LAV, and HMMWV. These antenna systems are designed in such a manner that the “directionality” of SATCOM antennae is reduced.

- Self-steering antennae will solve the "pointing" problem. Several organizations are pursuing this technology.

- A key Army program is the Digital Communications Satellite Subsystems (DCSS), deployed as part of the Defense Satellite Communications System (DSCS) to provide signal-processing equipment to interface to both DoD and leased commercial C and Ku band satellites. This is accomplished via the standardized tactical entry point, which prepositions secure voice, video, classified and unclassified data services to provide interoperability and strategic reachback.

A portion of the JTF WARNET initiative is focused on BLOS communications. Their intent is to provide all tactical level users access to national and theater level information. When available (prototype deployed in Western Pacific FY04), it will fill the role of bridging together the COPS for each of the Services. Its architecture will comply with existing and emerging DoD joint system standards including JTRS. The JTF WARNET effort is intended to leverage the best of existing C3 development work by all services. It is imperative that the USMC expresses their needs and requirements to the JTF WARNET program office at ONR.

4.5 Bottom Line

A multi layer, multi tier architecture is the optimal approach for addressing the BLOS communication problem. With this architecture, the Marine Corps will be able to utilize organic assets for the majority of their communications. Several BLOS communication options exist. Organic assets should include high altitude platforms, tactical UAVs (SWARM), as well as payloads. The BLOS payloads should be installed in the V-22 and H-1 series airframes. Both of these platforms will have the room to hold a small relay payload. More importantly, these platforms will be traveling along the same lines that the ground Marines are traveling. Hence, another airborne relay asset will be "visible" to relay needed communications.

Several BLOS options were detailed above. All have merit. Additional information is required before a final list of options is prepared. In addition, modeling each of the options would provide information valuable to POM preparation.

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5 THE BRIDGE TO THE FUTURE

JTRS and the WNW will become a reality and significantly enhance C2 across the DoD. Each service is dedicated to operating within the NCW arena. Large amounts of dollars and research are going into making this a reality. However, the JTRS program needs a great deal of planning and requirements work within each service to ensure that it will provide the expected functionality. There are numerous components which each service must develop requirements for and plan for production to make JTRS a reality. Even with JTRS, there is still a large gap between what will be and what is today. Bridging this gap will prove to be difficult. There are as many ways to approach the issue of transforming from stovepipe architectures to a true network centric architecture as there are engineers or planning staffs. Major issues that must be dealt with are the seamless data flow via the TDLs, MAGTF OC, seamless BLOS/OTM on the move communication between all units, and interoperability with USMC units and Joint/coalition forces.

5.1 Tactical Data Links

The way the Marine Corps will pass command, control, communication, and intelligence data will be through its TDLs (including VMF). These links can be roughly broken down into those used primarily by the ground community, the aviation community, and the intelligence community. Unfortunately, all utilize a different waveform requiring different receivers and display devices to make use of the information they pass. At any given time during an operation, information contained in one TDL must be passed directly to a participant of another TDL. Gateways are an efficient, stopgap approach.

Marine Aviation will participate on the Joint Cooperative Targeting Network (JCTN), JDN, and Joint Planning Network (JPN) levels of NCW networks. The JCTN level of engagement data distribution is best exemplified by the CEC and using the Link-16 (JTIDS and MIDS) network to distribute the shooter quality data to the network assets. The JDN situational awareness and C2 management exchange can be comprised of Link-16, the legacy Link-11 and Link-4 and high bandwidth data exchange links like Common Data Link (CDL). The JPN is focused on large numbers of users with large amounts of data but not necessarily real-time and can be exemplified by Integrated Broadcast System (IBS) and the Global Command and Control System (GCCS). Marine Aviation is actively participating in these networks and in working to ensure interoperability with the Navy, with the services, and with our Allies.

Perhaps the two most communication challenging missions for Marine aviation is CAS and Time Critical Targeting (TCT). Both these missions rely on real-time information, which is primarily derived from other than Link-16 sources. What is needed is the development of a joint service, cross-platform, TDL message processing and integration application. CLIP is one such application being developed by the Navy and USAF and will provide the interface to various tactical data communication systems including current terminals and radios and those under development such as MIDS SCA and JTRS, and will continue to act as a gateway providing translations and data forwarding to legacy systems. CLIP is planned to be the primary and consistent interface to any host (i.e. combat) system, and is envisioned to be primarily open systems software that can reside on any operating system or hardware. Common Aviation Command and Control System (CAC2S) can operate under this interface with appropriate planning and this should be done immediately.

Close Air Support provides an excellent example of the need for information to pass between the divergent TDLs of VMF and Link-16. Let us suppose there is no or limited interaction

between the ground forces and aviation. The ground forces do not know the status of friendly aircraft overhead. Strike information, including weapons load out and current targets of the CAS aircraft are not relayed to the ground. Voice circuits can be used to exchange some of this information, but even covered voice transmissions often give away the position of friendly ground forces to the enemy and can be very time consuming. Data link features, including receipt-compliance (guaranteed delivery) for Mission Commands can be critical to the success of a CAS mission and must be implemented across a gateway.

A major question is what link to use for ground to air ops. Link16 or VMF using something like DACT. Link-16 not only provides a link for SA but also is also designed and used for C2. It has a nominal 1Mb/sec capacity with a normalized 54-105Kbs utilized per user. VMF is primarily an SA link (Battlefield reporting) with a nominal 2.4Kbs to 7.2Kbs. Messages are designed for battlefield status reporting and are generally report vs. sensor track oriented. Our assessment is that Link-16 will provide the most cost effective method to control and pass information to and from aviation assets.

Joint interoperability is also an issue. The Army and Air Force have budgeted dollars and have plans in place to enable Link-16/VMF translation at the TACP level. They do not envision a time when a FAC would be outside of electronic range of the TACP vehicle. This is logical and consistent with the NCW architecture. With JRE and S TADIL-J, the possibility of BLOS connectivity for Link-16 message sets is an expected reality. Of coarse the best solution would be one in which it does not matter what format the FAC or AC passes or uses the information. This would be possible using an ubiquitous automatic information manager, which would get to them the information as they had need.

The Marine Corps' current use of the DACT to pass VMF data is an excellent alternative; but it should not be viewed as a complete solution. Currently only 3-4 lines of the 9 line are being passed. VMF also has neither message set for tasking/scramble CAS aircraft for immediate CAS nor any for code word or time used after initial AC check in or egress In Flight Report. There is also the issue of imagery. Link-16 has the capability to carry imagery. Imagery enhances the ability of the pilot to prosecute targets particularly when they are not preplanned.[7] While it is true that the FAC/TACP may not be the producers of this imagery having them be another node which can pass it on increasing the probability of its timely arrival. While we are not necessarily advocating complete electronic CAS TACP interactions Link-16 does provide the most robust control capabilities. Considering these few points one would need to ask why would the Marine Corps not want to follow the Army and Air Forces TACP program?

Figure 5-1 depicts the intricacies of the data that must flow in order to enable a netted fires mission during a STOM. During this phase of the STOM, you have both land and sea based operations center coordinating fires missions. As shown in the graphic, CAC2S goes ashore functioning as a Direct Air Support Center (DASC). It will be connected to the Navy Tactical Air Command Center (TACC), Air Support Control Section (ASCS) and ACE on board the ships utilizing UHF airborne relay of voice and TDL (Link-11 and16) via AJCN, ROBE, HAP and or JRE. Connectivity to the MEB GCE Fire Support Coordination Center (FSCC), Inf BN FSCC, and ARTY BN HQ will be via AJCN or HAP. These units will be passing EPLRS and or VMF message traffic such as unit position reports, fire requests, tactical information and Battle Damage Assessment (BDA). The airborne platforms will need to function as Point of Presence (POP) Vehicles (-V) as well as have Joint Enhanced Core Communication System (JECCS)

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capability. POP-V and JECCS capabilities can be deployed on HMMWVs but this approach is not recommended for forces separated by distances greater than 30 mile or in rough terrain or urban areas. Aircraft will be controlled via Link-16 with forwarding as required preferably by AJCN or HAP platforms. CAC2S should act as a gateway for VMF to Link-16. The DASC will pass such things as tactical information, A/C tasking, fire support coordination measures, and mission number. Strike Control and Reconnaissance Aircraft (SCAR) will be netted to both shore based and ship based operation centers. Utilizing Link-16 and SATCOM they will pass tactical information, BDA, fire support requests, status reports, etc. They also will receive data from netted sensors.

> Point Of Presence is a term that is commonly used in the internet industry to denote a central facility or hub which subscribers use to access the internet provider's. In our application, it is where subscribers are linked to the POP by a wireless connection and the broadband backbone is provided by high bandwidth wireless link.
>
> JECCS: The Joint Enhanced Core Communications System is a small footprint, affordable communications system for the U.S. Marine Corps providing joint forces with mission connectivity requirements of a "first-in" capability. JECCS facilitates a robust command and control capability for USMC Marine Expeditionary Units (MEU) and Marine Expeditionary Force (MEF) forward headquarters. It is designed to fit into current and planned communications architectures and support ease of transition from a small force to a larger sustained force. The JECCS C4I system provides a deployed force operating both at sea and ashore with a mobile high bandwidth satellite communications capability and uses the AN/UYQ-70 family of COTS-based military equipment, which has been proven in harsh military operational environments at sea and ashore.

Initial aircraft control will primarily be from the ship based assets using naval resources via Link-16 and providing CEC via the Command and Control Processor (C2P) with the added advantage that the Common Network Interface project will enable. CAC2S will also be used by the ACE for planning while ship based. As the forces move further ashore, ACE functions may move a shore and take over tactical control of Marine aviation. CAC2S enables this transition since it allows for multi-function MACCS agencies. This flexibility allows the ACE commander to move with the forces as required with relative ease. For example, TACC functionality can be preformed along with DASC functionality from the same operations center. In order for CAC2S to perform all the same C2 functions as those found aboard ship it will need to ensure interoperability with current Navy funded efforts to enhance CEC functionality.

Figure 5-2 illustrates a view of the controller interaction and the nets needed for a CAS mission. Communications between the TACP and CAS aircraft in terminal phase is complicated by the fact that direct, line-of-sight, communication distance between a TACP and fighters on a CAS mission will probably be limited to 20 miles or less in most cases. This gives pilots little time to assess and understand the situation after receiving updates from the TACP. It would significantly improve the pilot's understanding of the situation, and therefore increase the likelihood of mission success if data linked information could be received reliably in the cockpit at a range of 100- 150 miles from the TACP rather than at a range of 20 miles. To do this, it is necessary to relay Link-16 messages between the TACP and fighters to achieve reliable communication over longer distances. CAS aircraft must be in direct contact with the ground maneuver units as well as their own aviation C2 chain.

In analyzing the communications requirements for CAS, it is clear that, because of LOS limitations between the TACP and CAS fighters, communications between them must be relayed to be reliable. The requirement to relay certain CAS information exchanges has a significant impact on the Link 16 network architecture. Adding a CAS subnet to the architecture will help facilitate the passing of critical ground targets, troops, points of interest/designated ground targets from the TACPs. The flight will contact the TACP on a CAS subnet by selecting a specific CAS Participation Group (PG) net number in the cockpit. The CAS flight's Controlling

Unit (CU) will provide the net number. This will cause their Link-16 terminal to transmit and receive in the CAS PG using the selected net number. The CAS subnet will be used by the TACPs to transmit mission assignment data including target location, friendly and civilian locations, the initial point, etc., directly to the CAS aircraft. These mission assignments will be addressed to the flight leader leaving no doubt that they are mission related. The flight leader, using machine receipts in donated time slots, will acknowledge transmissions on the CAS subnet. The TACP can also verify receipt of information in assignment messages by voice. This may be the primary means of verifying receipt of critical information during the two or three minutes before weapons release. During the terminal control phase of the mission, the CAS aircraft will be in digital contact with its final CU, e.g., the aircraft performing airborne command and control functionality, on the control subnet and with the TACP on the CAS subnet at the same time.

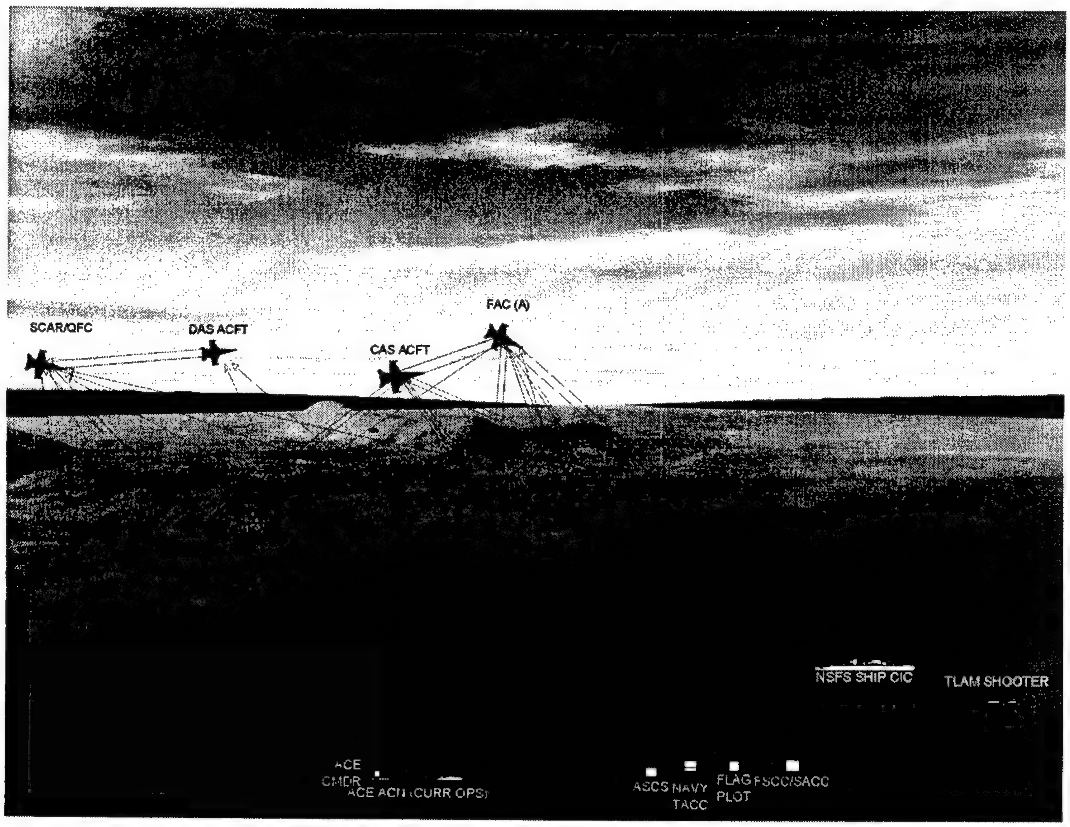

Figure 5-1 STOM Operational View

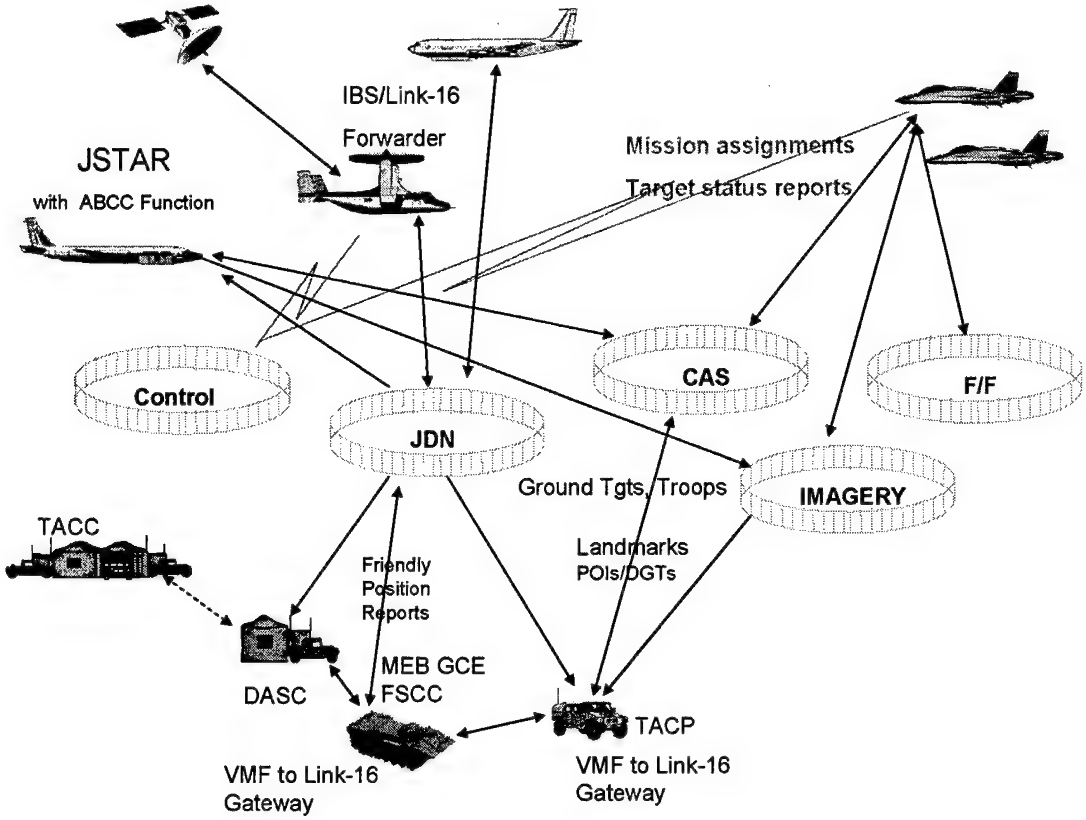

Figure 5-2 CAS Controller Interaction

Gateway functionality between VMF/EPLRS and Link-16 is needed down to the controller level. Technologically this is not a difficult task. The following diagram illustrates a simple gateway.

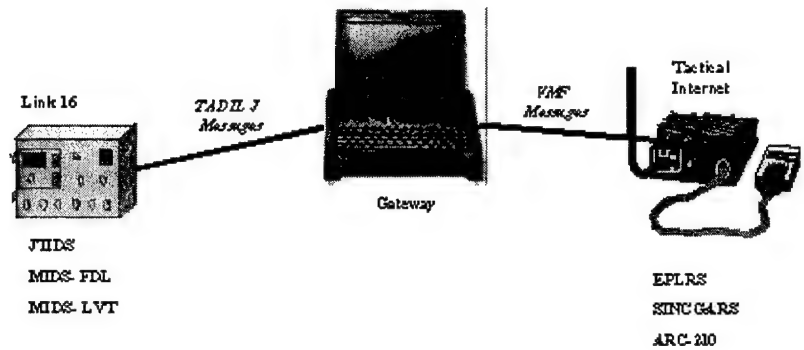

Figure 5-3 Trivial Gateway

Aviation representation in the Joint Tactical Data Link Working Group Gateway Group is needed to insure aviation needs are voiced. Current efforts have been aimed at data forwarding of TDLs and not true gateway functionality. As seen from the previous discussion, this is where the Army and Air Force are headed. The Marine Corps has also stated this need in the JTRS C4ISP: "The TACP vehicular communication system must support a two-way crossband capability to support gateway operations, including Link-16 to VMF, Link-16 to EPLRS, and Link-16 to SADL. Note, however, that all gateway functions will be performed by TACP computers; TACPs will rely on the Cluster One radio merely as a "data pipe" providing access to various radio communications modes, and not as a gateway that can translate between message formats." The ability of the terminal controllers to communicate via Link-16 will ensure total joint interoperability from transition to the complete 2020 architecture.

The Services are consolidating the number of data links down to four major links. Two of these major links are Link-16 and VMF. These two networks will be installed together. It will become imperative to have trained personnel that understand and can manipulate multiple data link networks rather than the traditional single link network.

5.2 MAGTF Operation Center

In order to complete the C2 architecture the Marine Corps needs to revisit the merging of the UOC and CAC2S into the MAGTF OC. The concept of command centers with the same real to near real-time CTP across the battle space is important to the NCW view of future operations. Currently the UOC is not budgeted to provide Link-16 connectivity. As seen in Figure 5-4 this will lead to a CTP which is delayed due to its need to receive the air picture from other sources. Current CAC2S requirements allow it to receive both VMF/EPLRS and Link-16 data in order to form its fused view of the battlespace.

Similarly, the EFV(C), since it will have the same basic functionality and is planned to act as a command center, would benefit from planning and budgeting Link-16 capability into its program. The EFV(C) is being outfitted to function as a DCOC. In keeping with a CTP, the DCOC program should also look at implementing MAGTF OC functionality rather than a non real-real time C2 picture from the UOC.

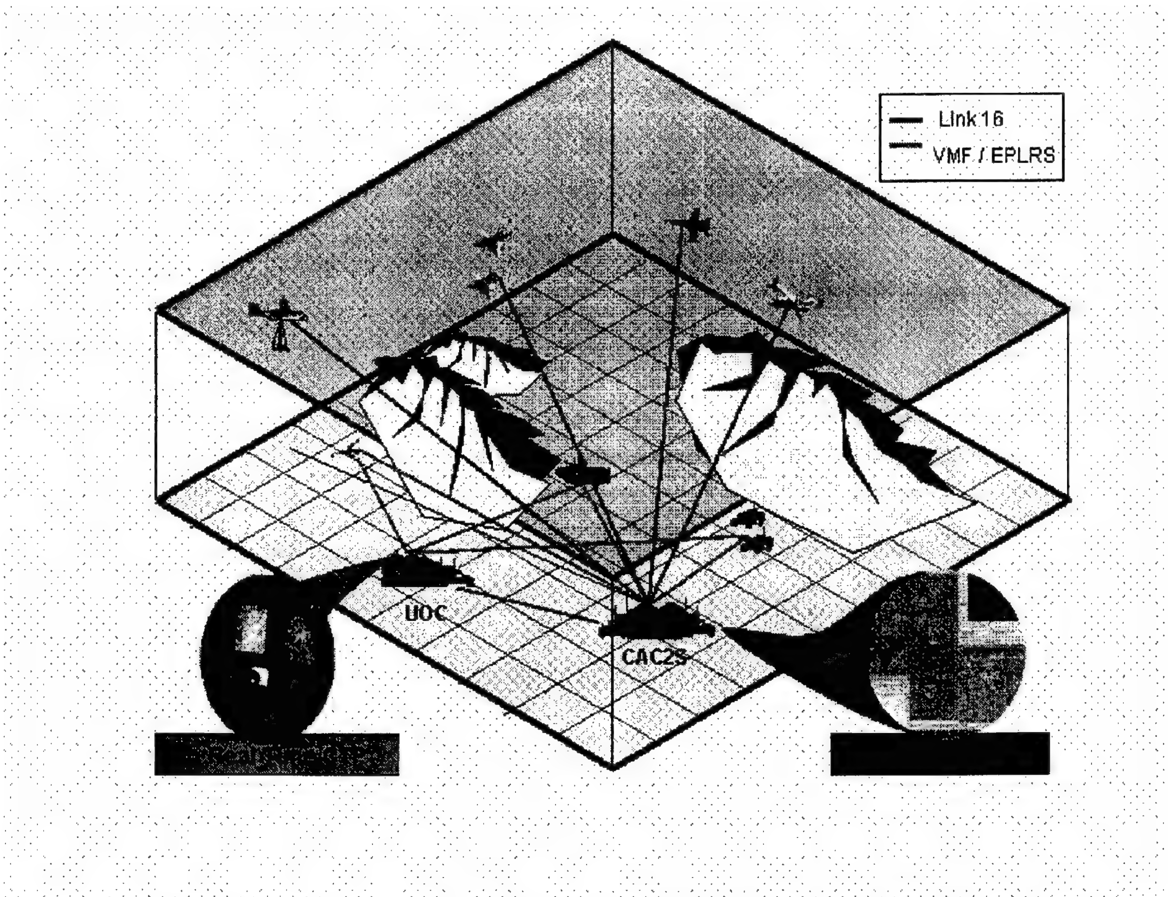

Figure 5-4 UOC vs. CAC2S Tactical Pictures

Figure 5-5 depicts a simplified view of how all the organic pieces could fit together with relative coverage by the various relay platforms. During a STOM operation, the first aircraft operations will most likely be doing preparation of the battle space. DAS aircraft will begin to attack targets that may be quite deep. Communication and control of these aircraft would be enhanced by deployment of ROBE equipped tankers and organic UAV/HAP assets. As forces begin to move ashore C2 on the move functions through the EFV(C) and the MV-22 (equipped with CAC2S) will begin to occur. (See Figure 5-6) The ability of the shipborne and land/air based C2 platforms to exchange all TDL types will provide great redundancies as well as insure a common picture across the entire battle space.

For a MAGTF OC to happen, well thought out requirements must be developed and put in place soon. It is during this process that the unique pieces of CAC2S and UOC will be identified. Once the requirements are fully documented, the MAGTF OC can be constructed. All C2 platforms can then draw on a common software/hardware load.

5.3 BLOS On the Move Communication

STOM requires continuing communications between the ship based C2 structure and the assaulting forces. As seen in the following graphic, the ships are outside of LOS. There are multiple ways to solve this problem. One would be to use the traditional ground based communications relay sites utilizing such things as the AN/MRC-142 UHF LOS MUX. Another is to depend upon satellite relay. While yet another would depend upon a group of UAV or manned airborne platforms to support relay functions.

See BLOS section of this document for complete details of options and recommendations to solve the BLOS problem.

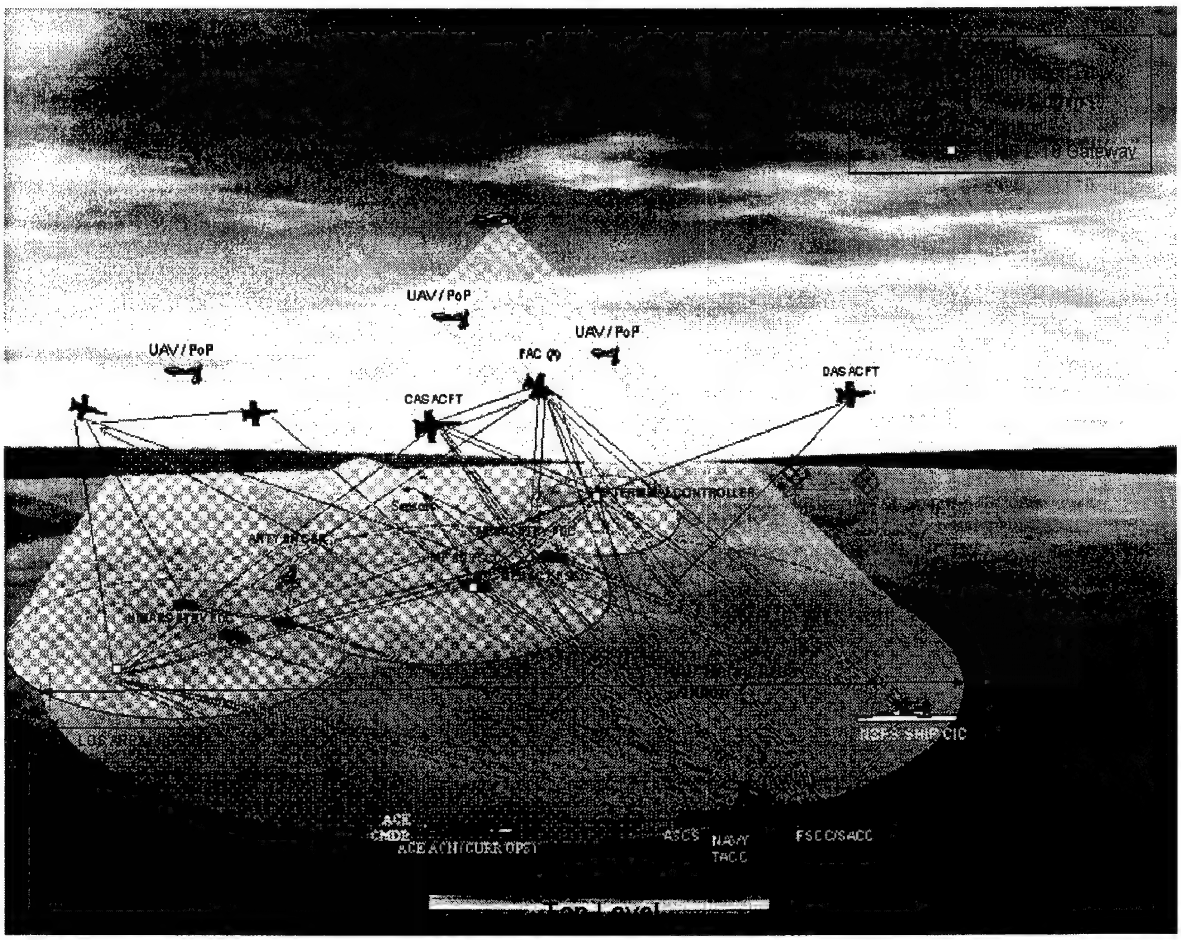

Figure 5-5 Top Level Architecture

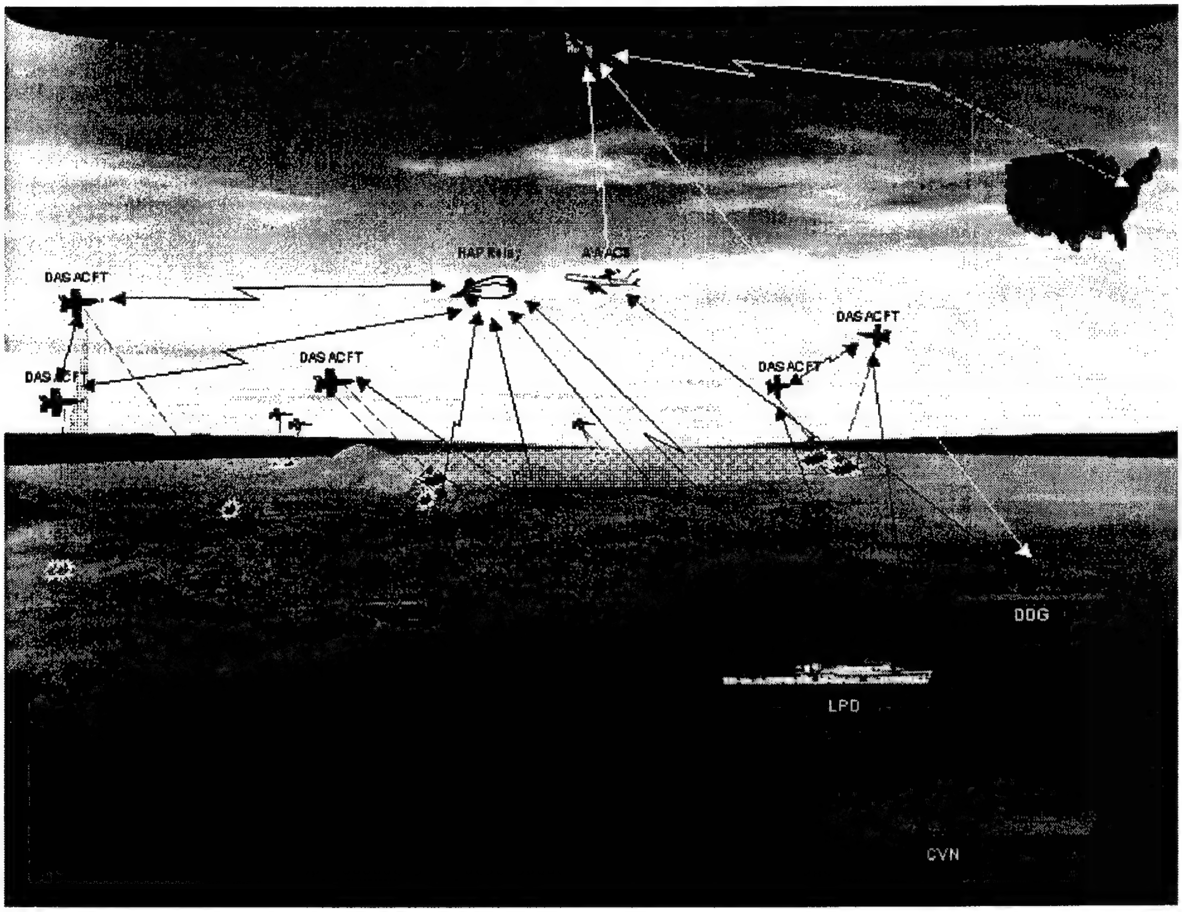

Figure 5-6 Battlefield Preparation

5.4 Gateways

IBS to Link-16/VMF participants use non-interoperable message sets and media for information exchange. The gateway facilitates interoperability by enabling information exchange over whichever means are available to data link participants -- from the most time-sensitive threat data to the lowest priority general intelligence information.

The gateway provides seamless, automated information exchange among users of the message sets listed below (as referenced in the OASD/C3I Joint Tactical Data Link Management Plan):

- J Series (Link-16)
- K Series (VMF)
- E Series (IBS)

Potential battlefield deployment locations for the placement of a Tactical Data Link (TDL) interoperable gateway function include airborne C2 nodes (Unmanned Aerial Vehicles (UAV), Joint STARS) and ground C2 nodes (DASC, TACP). To reduce the potential flooding of the Link 16 network, it is recommended that only limited information that is of interest to the entire Link 16 community is forwarded from the Tactical Internet/VMF to the Joint Surveillance Net (JSN) (The surveillance portion of the JDN) of the Link 16 Network. Mission specific C2 data exchanges (e.g., Mission Assignment and WILCO/CANTCO) and limited reporting of friendly and air defense entities around a target would be exchanged only on stacked control and/or fighter/fighter subnets of a Link 16 network.

Multiple gateways can be simultaneously used for the exchange of information on fighter/fighter and control subnets. When aircraft are directed to change controllers (either digitally or by voice), they are also instructed to change their Link-16 Control subnet. The net number that matches that assigned to the gateway (e.g., Battalion TACP) is then selected by the aircraft (automatically) or by the pilot. That net number change is reflected in aircraft Precise Participant Location and Identification (PPLI) transmissions on the net being monitored by the gateway. One gateway has no knowledge of any other and is not dependent upon exchange of information or events with other gateways. Information exchange between the controller and the aircraft include:

- Initial and updated/refined target information.
- Limited number of friendly positions in the vicinity of the target.
- Hostile air defenses in the vicinity of the target.
- Target engagement status.
- Real-time BDA data.

A single gateway would be assigned as the forwarder for information to be broadcast on the JSN. The most likely candidate would be a UAV, with a Joint STARS or DASC as potential backups. A UAV with a multi-mode, multi-band radio would be an ideal location as it meets the LOS and limited distance requirements of EPLRS (85 miles). Defense Advanced Research Project Agency (DARPA) is planning on having three vendors demonstrate a multi-band, multi-mode radio (including Link-16) on an airborne communications platform next year. The airborne multi-band, multi-mode JTRS planned to be available by 2005.

Table 5-1 illustrates what Gateways are required to support different mission areas. A suggested total list of information exchanged on the various Link-16 subnets is listed in Table 5-2. This list of messages is based on the IERs developed to support an Advanced Concept Technology Demonstration (ACTD) (occurred in FY98/99) that demonstrated the Gateways products supporting the message exchange between Link 16/VMF, and those submitted to the Joint Multi-TADIL Standards Working Group by HQ AC2ISRC/C2GT.

Table 5-1 Required Gateway Support by Mission Area

Mission	Gateway Between VMF/EPLRS and Link-16	Gateway Between Link-16 and BLOS Support	Gateway Between IBS and Link 16
CAS: Targeting and ground SA to CAS fighters; pass BDA to TACP	X		
CAS C2 messages	X		
Ground SA (local and limited theatre- wide)	X	X	
TRAP: Location of aircrew and SA	X	X	
Interdiction/TCT: Re-task aircraft in flight BLOS	X	X	
SEAD: SAM sites and amplifying information		X	X
TACC/TAOC/DASC Support	X		X

Table 5-2 Information to be Exchanged

Link-16 Network	IER
Joint Surveillance Net (JSN)	From Link 16 to VMF PPLIs (Air, Ground, Surface) Tracks (Air, Ground, Surface) Emergency Point Threat Warning
	From Tactical Internet to Link 16 Position Reports for friendly fixed wing and rotary wing Aircraft not generating PPLIs on Link 16 *Attack Helicopters* *RECCE Helicopters* *CAS Aircraft (e.g., AV-8B)* Updates to the FLOT, FEBA, FSCL Mayday messages (downed aircraft) Threat/Strike Warnings, Nuclear, Biological, and Chemical (NBC) Warnings Notification of NBC Contaminated Areas
Control Subnet	From Link 16 to Tactical Internet Request for Position Reports of Friendlies around a self-assigned target Aircraft on Station WILCO/CANTCO

Link-16 Network	IER
	Battle Damage Assessment (BDA) From Tactical Internet to Link 16 Position Reports of Ground Friendlies Sightings of Ground Hostiles/Unknown Mission Assignment Manual Position Reports of Ground/Hostiles/Unknowns near Target
Fighter/Fighter Subnet	From Link 16 to VMF Lock on target Weapon Released

5.5 Interoperability

Interoperability is both a principal rationale and defining attribute of the GIG. However, achieving the level of interoperability envisioned for the GIG is one of the challenges addressed here. The following paragraphs offer some guiding principles for meeting that challenge.

5.5.1 Define and Protect Interoperability

Interoperability requirements must be defined clearly enough to guide capability development and to enable effective compliance testing. The starting point in defining interoperability requirements is a Capstone Requirements Document (CRD) for each Joint Mission Area (JMA), and equivalent documents for the Joint Support (Business) Areas. The CRD defines the general operational concept and capabilities needed to carry out the mission with enough detail to determine general information-sharing and collaboration requirements.

It is important to protect interoperability in every phase of capability development. The battle for interoperability can be lost in any one of the capability-development phases, from conception through spiral evolution. Only by establishing methods that promote and protect interoperability in every phase can one hope to deliver truly interoperable systems and, hence, effective mission capabilities. The following paragraphs present recommendations for addressing each phase of the process.

5.5.2 Global Information Grid

To achieve interoperability of GIG information services, all elements of the service-communications, computing, network management, information management, information

assurance, applications, and interfaces-must be addressed. A lack of interoperability in any of these can prevent information sharing and collaboration.

5.5.3 Family of Systems Testing

Each member of the MACCS FoS is tested individually to determine if its key performance parameters are met. However, to assess interoperability as well as the other dimensions of a required capability, compliance testing must be conducted on the family as a whole. This will require a FoS test plan and facilities to conduct FoS testing.

The testing must be rigorous and independent to ensure that the warfighters receive the needed capability. The knowledge that their system(s) must pass a rigorous compliance test before approval for production should provide an incentive for program managers to pay careful attention to interoperability in the development phase.

5.5.4 Gateways

Until interoperable C3 systems have been deployed fully by the services, gateways will be needed to translate between non-interoperable systems. Gateways are often viewed as undesirable due to their potential to act as bottlenecks or single points of failure. However, given the rapid change inherent in information technologies, it becomes obvious that some degree of reliance on gateways will be necessary in most FoS entities.

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